VOL. XXXV. No. 12. DECEMBER, 1957

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THE STRUCTURAL ENGINEER

THE JOURNAL OF THE
INSTITUTION OF STRUCTURAL ENGINEERS

Visit of the President to Africa,
August and September, 1957

The Effects of the Wheel Tread Profiles and other factors on the Long Travel Motion of Gantry Cranes
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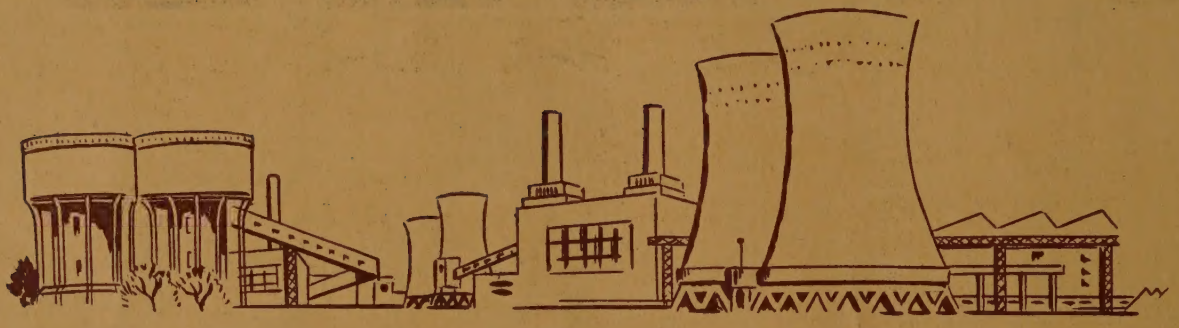

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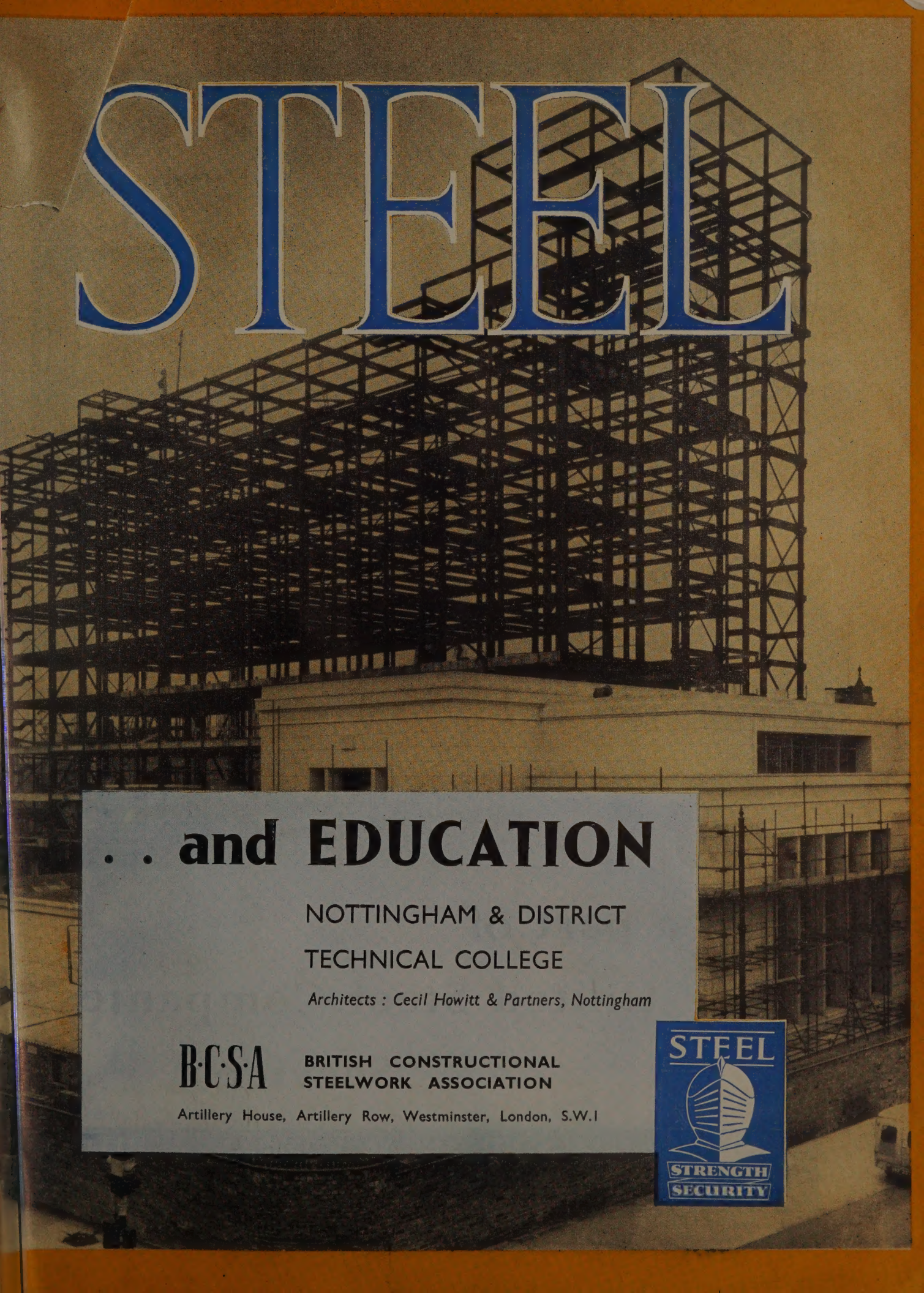

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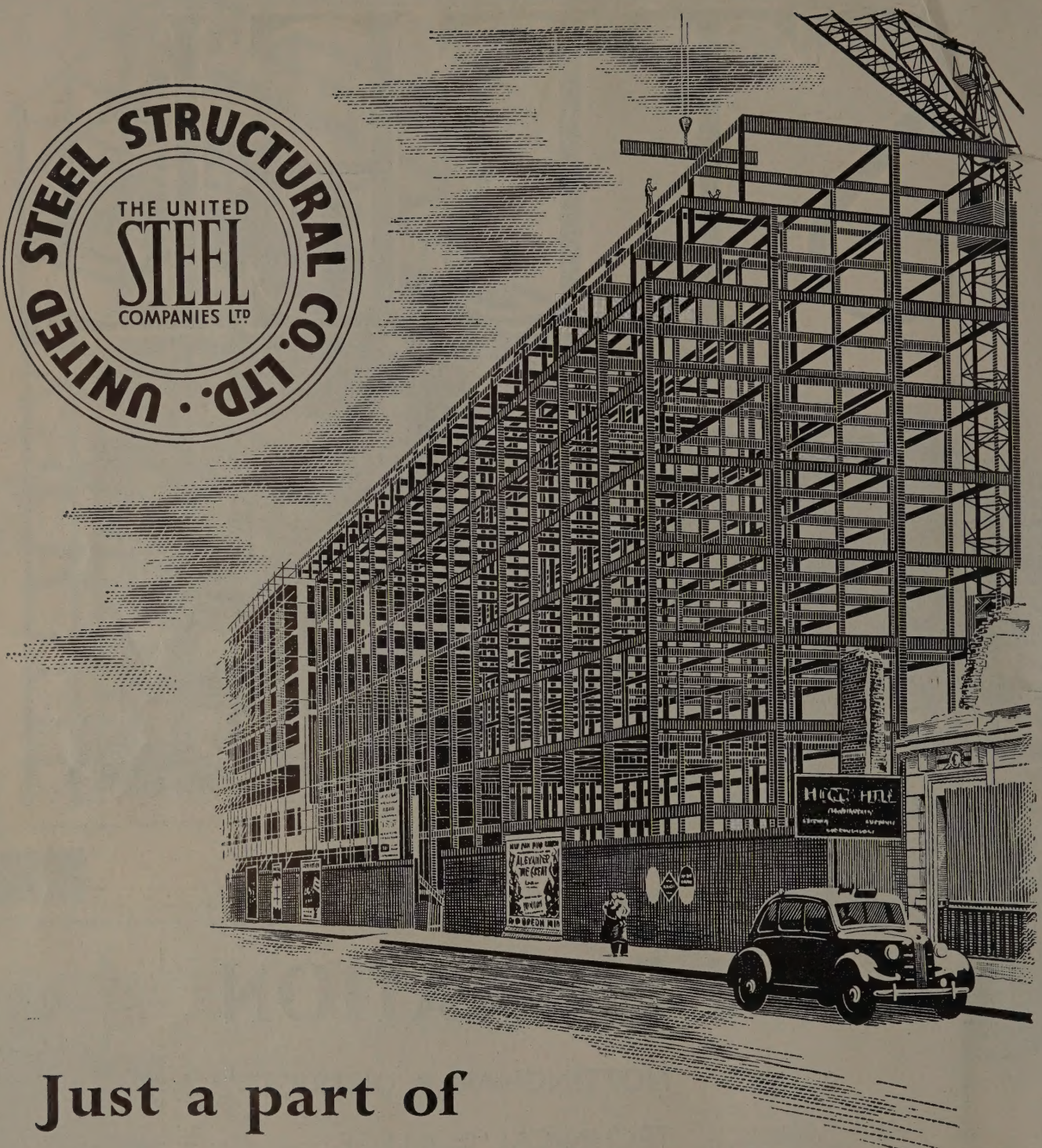

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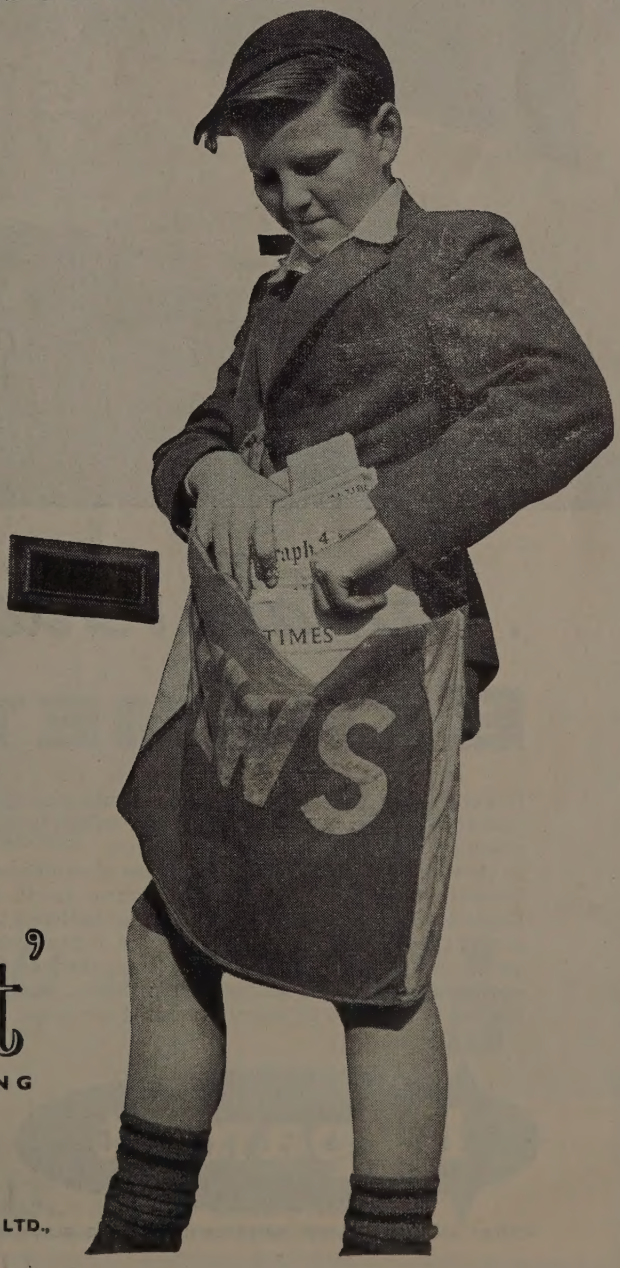

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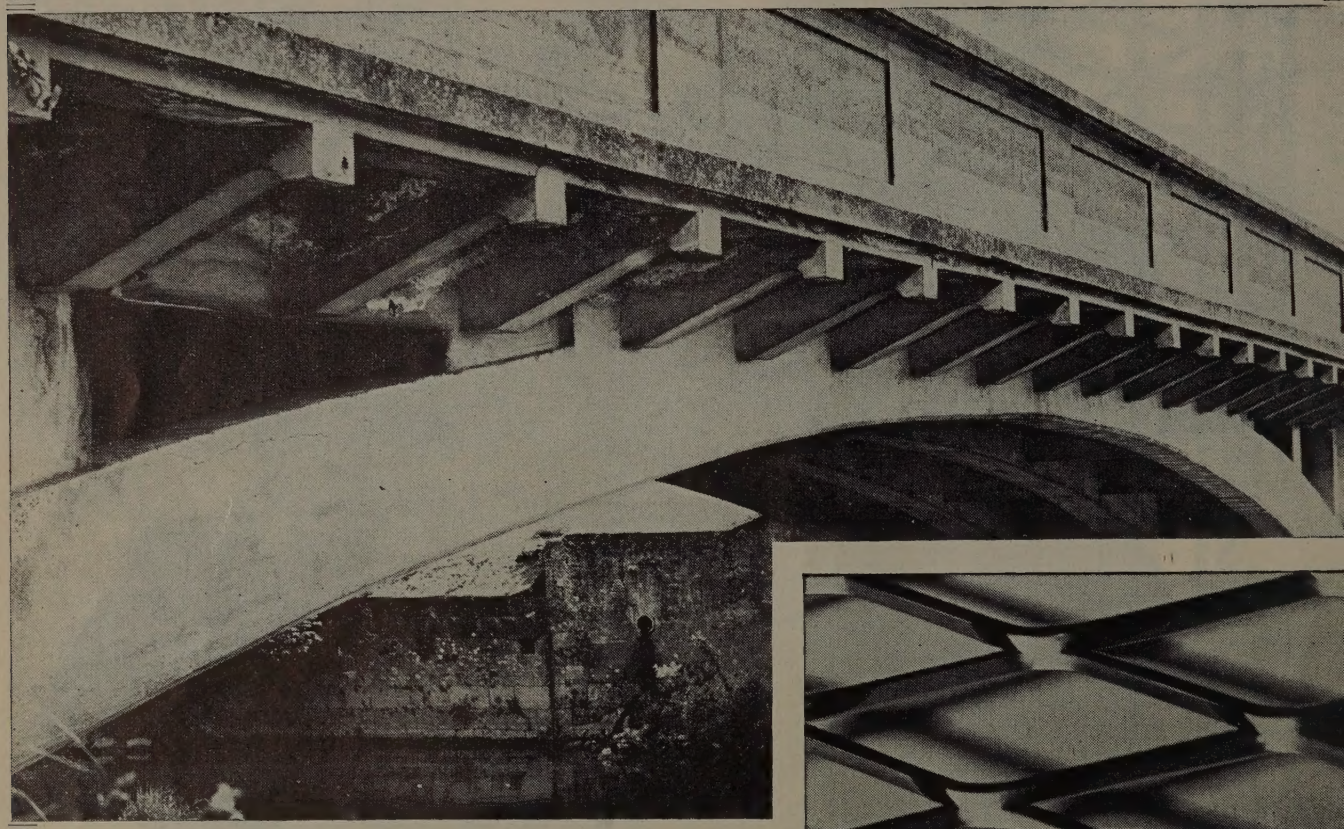

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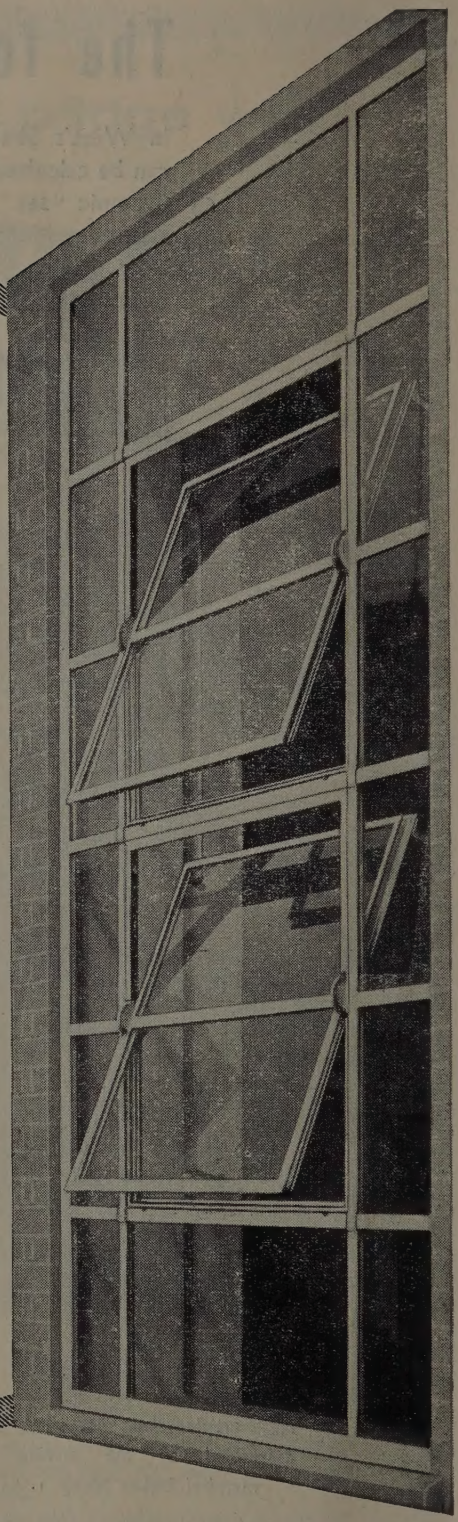

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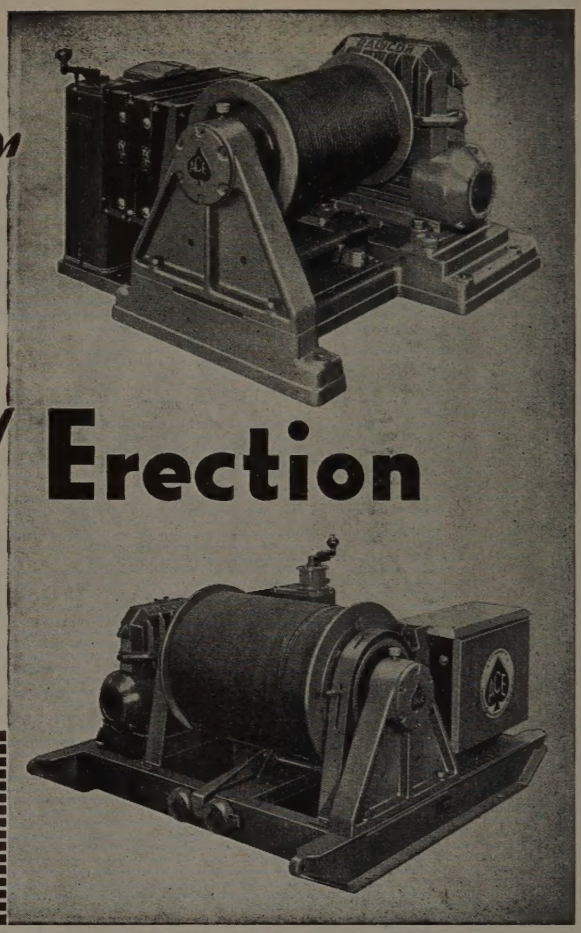

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Right: BUTTERWALK: Architects: David Evelyn Nye & Partners.

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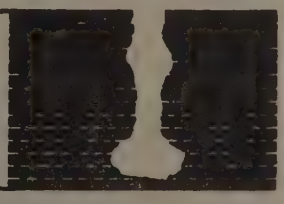

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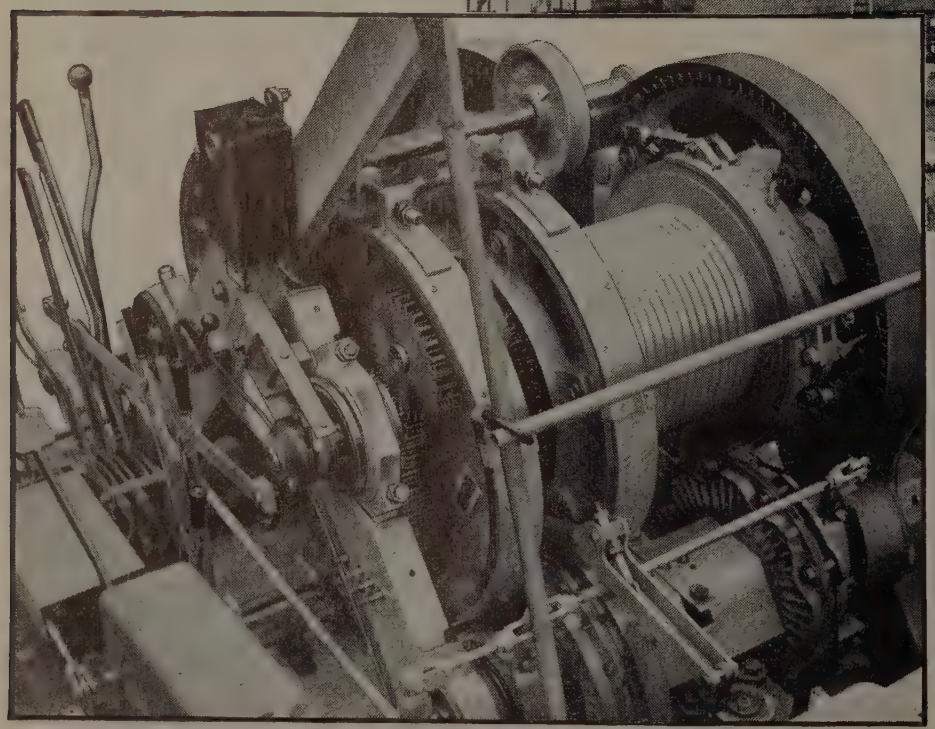

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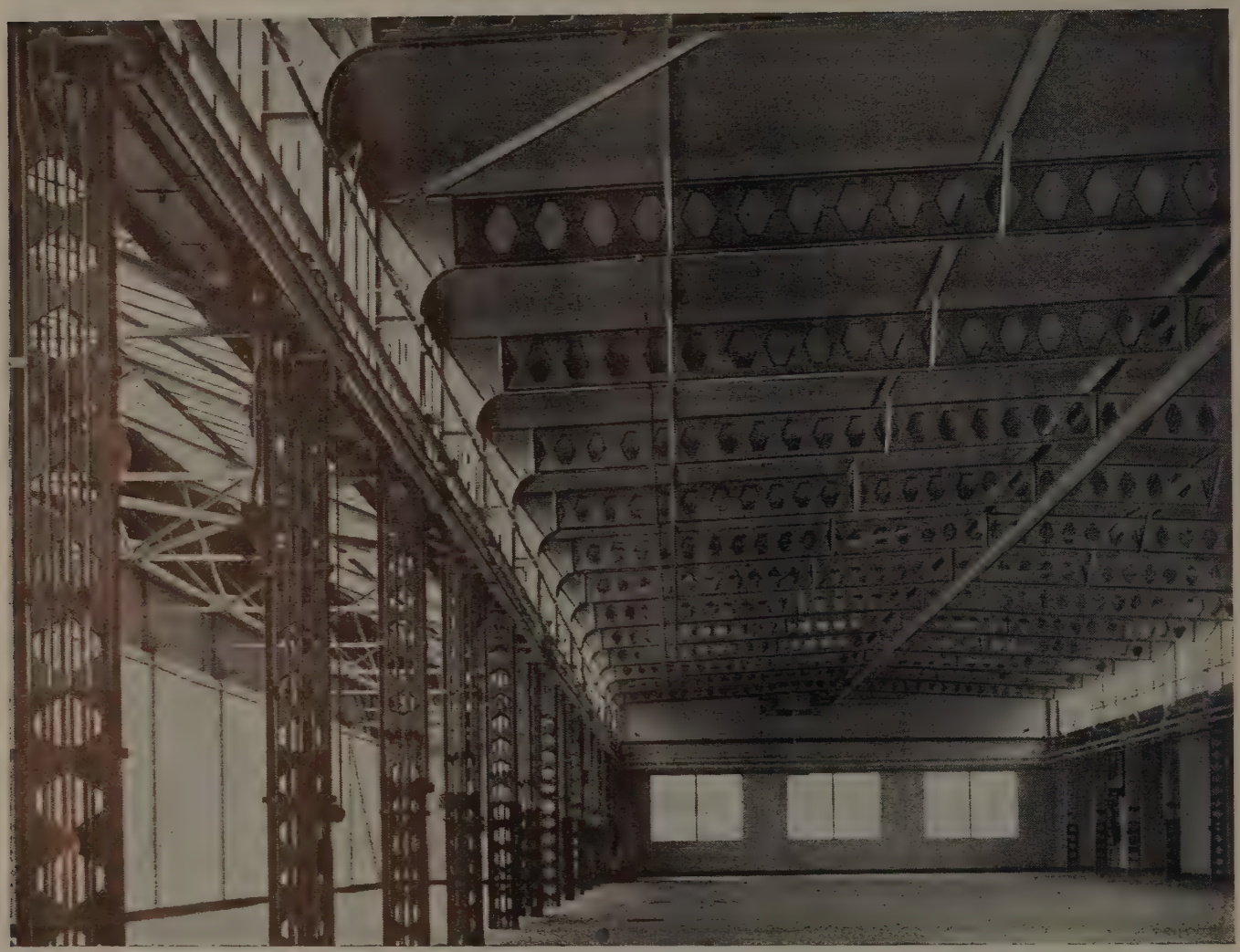

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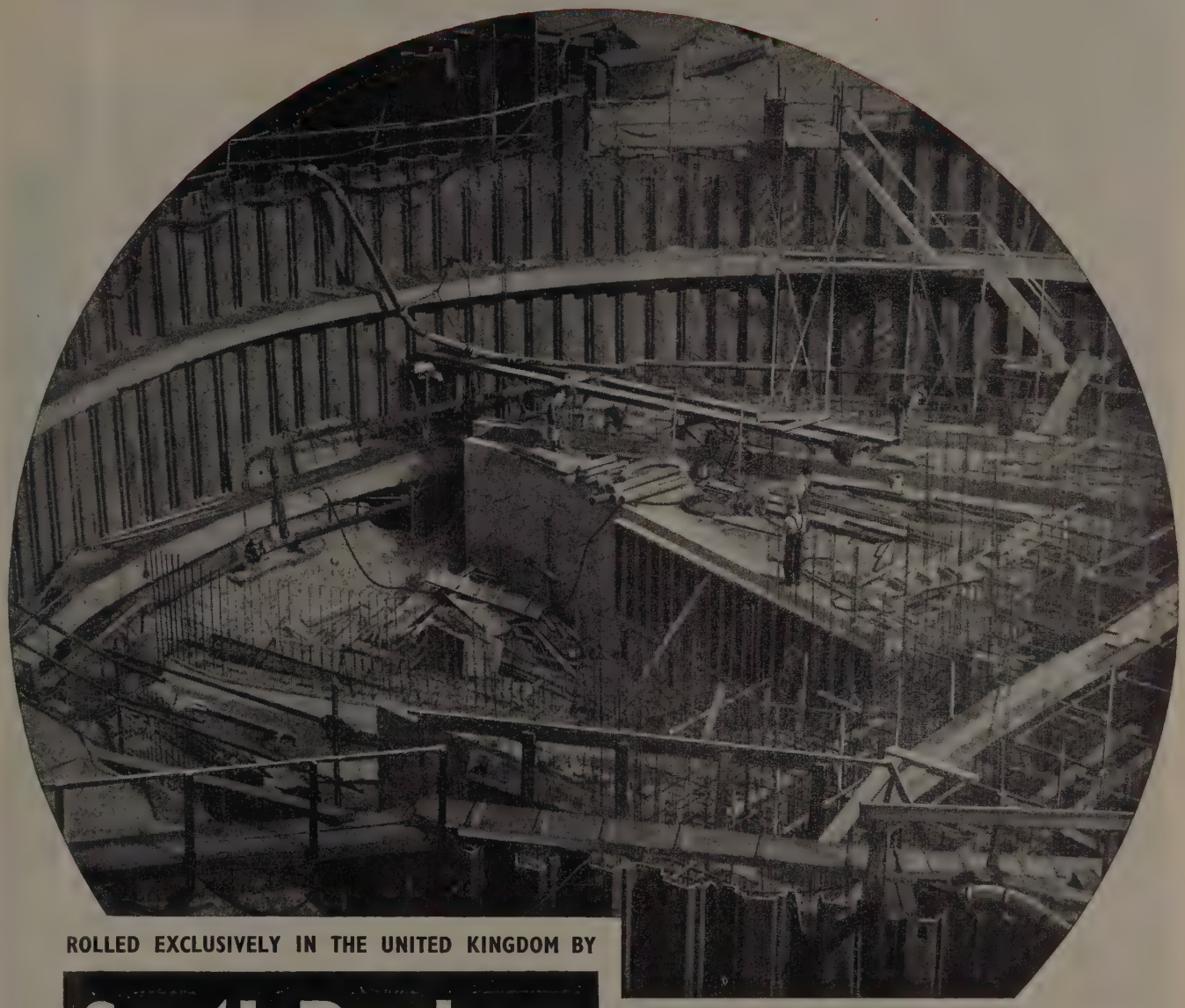

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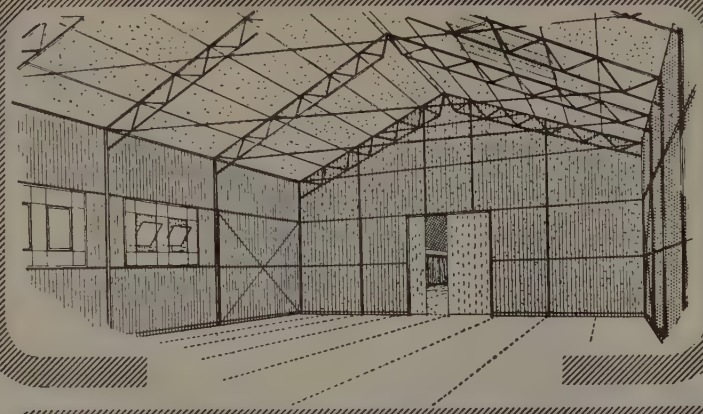

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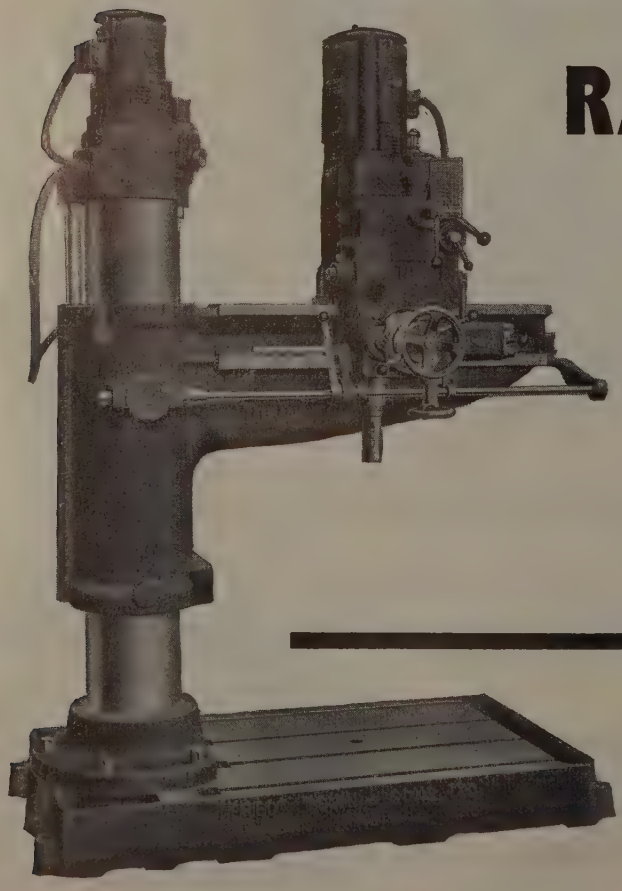

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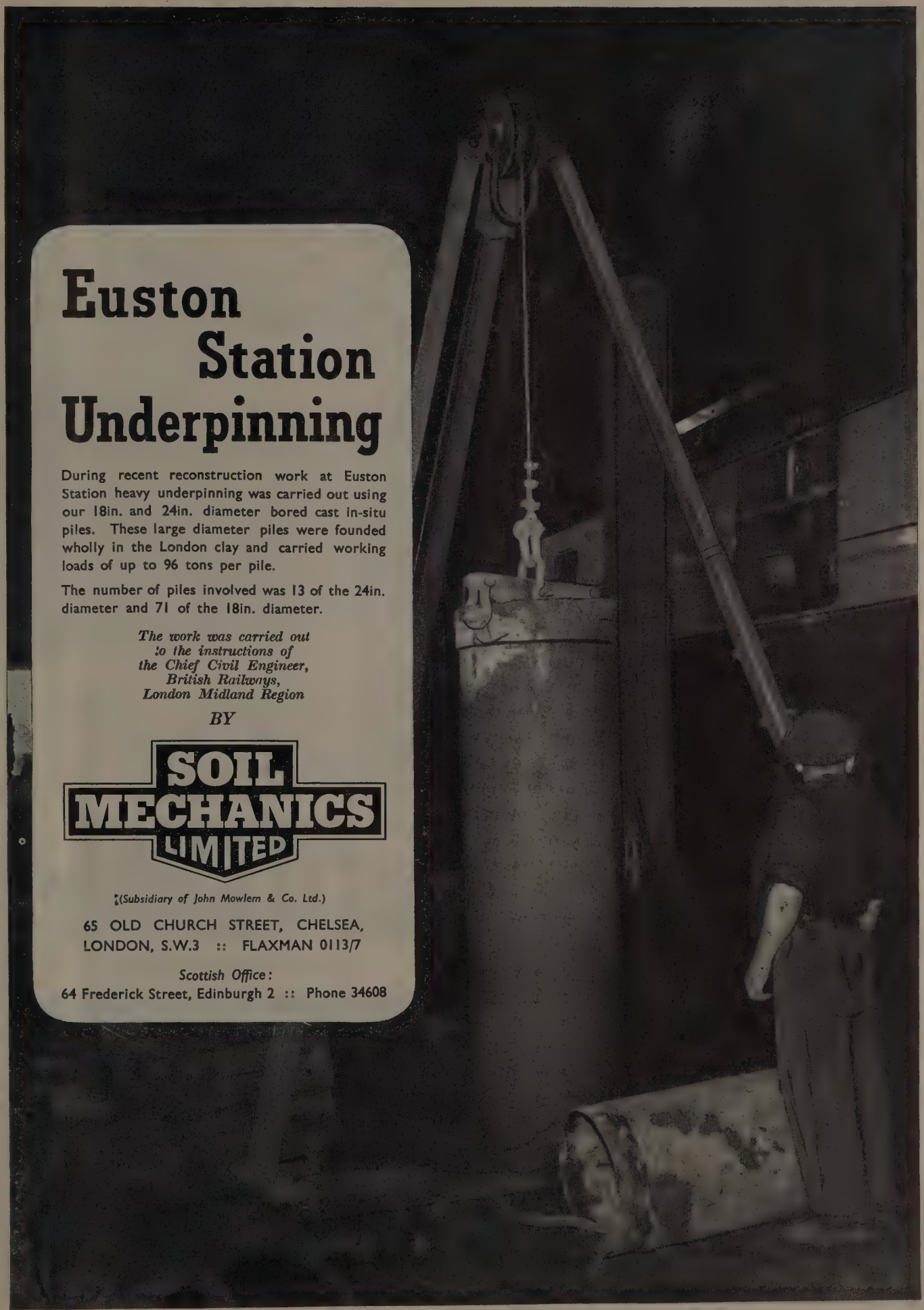

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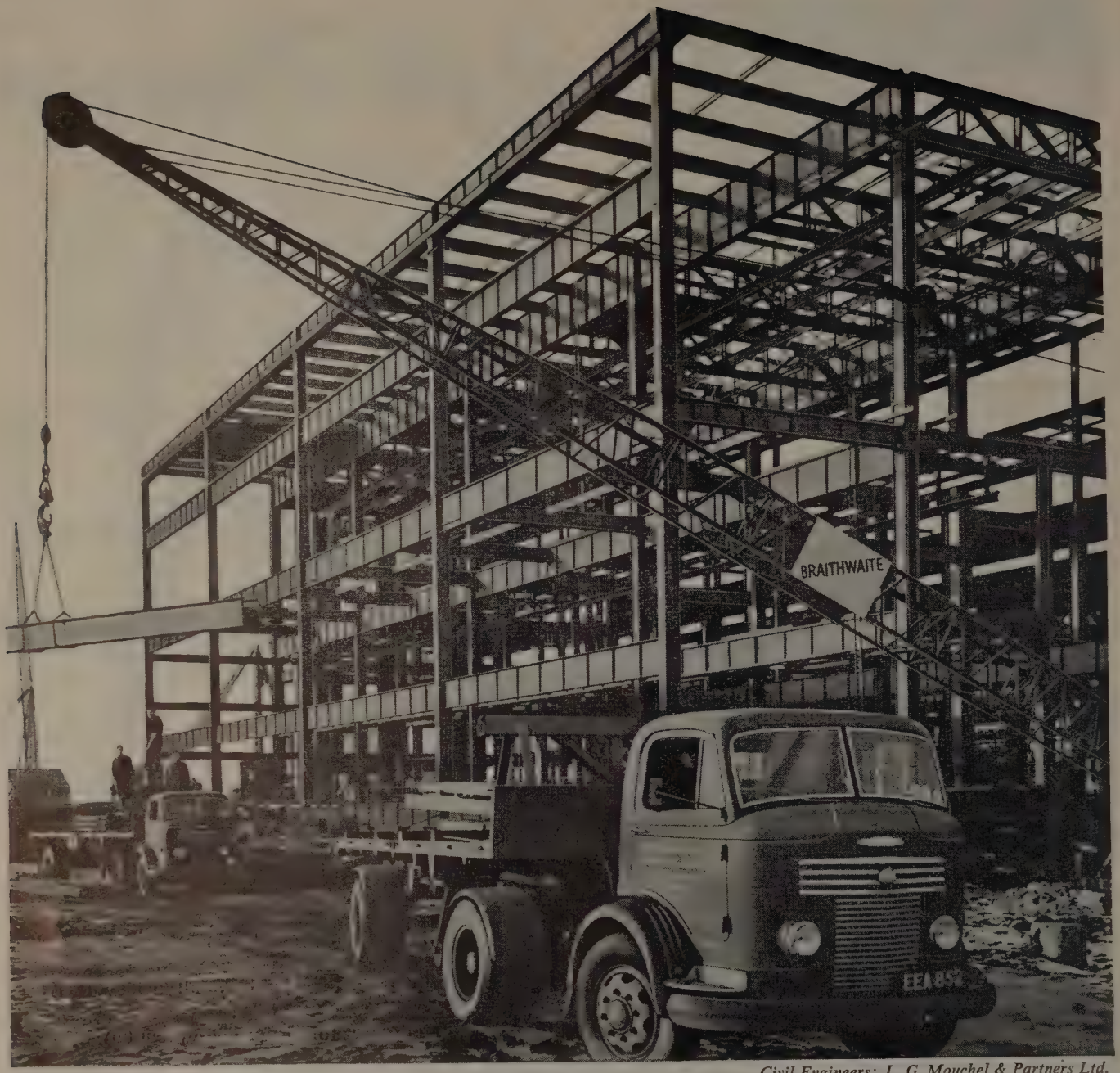

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All Editorial communications should be addressed to The Editor, The Structural Engineer, 11, Upper Belgrave Street, S.W.1. All MSS. should be typewritten and algebraic signs and formulæ be indicated distinctly.

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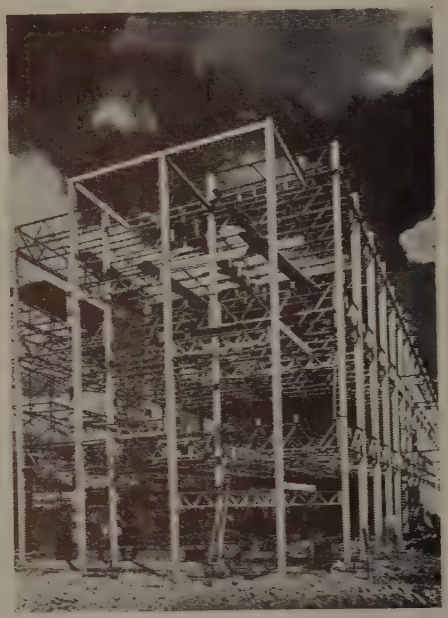

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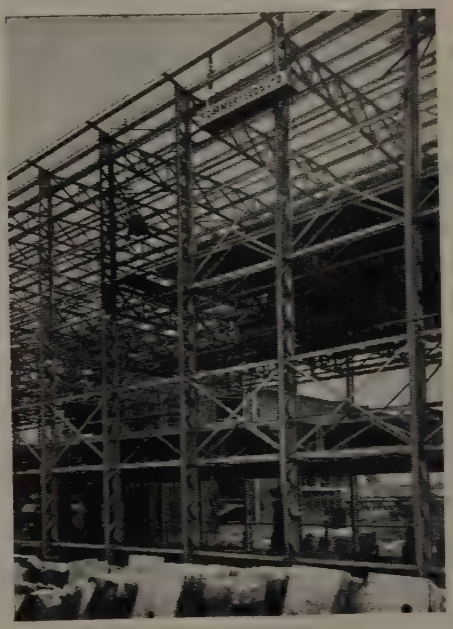

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Visit of the President to Africa
August and September, 1957

A FORMAL request was made by the Union of South Africa Branch on 11th January, 1956, that a visit to the Union by the then President, Mr. Stanley Vaughan, and the Secretary, Major R. F. Maitland, should be undertaken and would be greatly appreciated by Branch members. Owing to business commitments, however, Mr. Stanley Vaughan was unable to accept this invitation. The Union of South Africa Branch was informed on 2nd March, 1956, that Mr. Guthrie Brown, the 1956-57 President, and his wife, accompanied by Major Maitland, would be glad to visit Africa during August and September, 1957.

Preliminary arrangements were put in hand accordingly but, unfortunately, the illness of the Assistant Secretary, Mr. H. R. Gray, which has necessitated his leave of absence from the Institution, together with the impending retirement of Colonel Tosh towards the end of 1957, made it necessary for the Secretary reluctantly to cancel his proposed visit in order to cope with Institution business at Headquarters.

As it was convenient in any event for Mr. Guthrie Brown to visit Africa in the Autumn of 1957 in connection with hydro-electric and other works being dealt with by his firm at Owen Falls, Kariba and elsewhere, he very generously arranged that his tour of Africa, on behalf of the Institution, would be undertaken by him without any charge to the Institution Funds.

The previous visit of a President to Africa was when Mr. Leslie Turner and the Secretary toured South Africa during April and May, 1950.

The President, Mr. Guthrie Brown, accompanied by his wife, left London Airport for Nairobi on 1st August. Their tour covered Uganda, Kenya, Rhodesia and the Union. They left Cape Town on 6th September in the " Pretoria Castle " and arrived at Southampton on 20th September. During their five weeks' tour in Africa they travelled by air, road and railway over wide areas of the Continent from Murchison Falls, 180 miles north of Lake Victoria in the North, to Cape Town in the South. The total extent of their tour overseas amounted to about 16,000 miles.

The outstanding feature in every part of their tour was the friendly reception extended to them with the overwhelming hospitality for which South Africans are world famed. The warmth of the welcome which they received is a testimonial to the high regard which is felt for the Institution of Structural Engineers in all parts of Africa, and which was deeply gratifying to the President.

On the arrival of the President and Mrs. Guthrie Brown at Nairobi Airport on 2nd August, they were met by Mr. C. W. Cassé, Mr. Guthrie Brown's resident Partner in Kenya, and by Mr. R. A. Sutcliffe (Member) Chairman of the East African Section, and also interviewed by the Press.

The President and his wife stayed at his Partner's house in the outskirts of Nairobi, and for the next few days dealt with his own business matters, which included a visit to the Owen Falls Hydro-Electric project at Lake Victoria in Uganda. While there, they were taken by plane from Entebbe to Wangkwar Airstrip near Paraa Lodge about 180 miles north of Entebbe. There they had a memorable launch trip up the Nile to Murchison Falls where game of all kinds were seen on each bank, including crocodile and hippo in great numbers. Returning by plane from Entebbe on 7th August, the President was met by Mr. Sutcliffe, who showed him some of the interesting structural building work in progress in Nairobi. During the evening the President gave his lecture entitled " Hydro-Electric Schemes in Britain and Africa." The lecture, with coloured lantern slides, brought out the great advance, in the attention given to appearance and to amenities, of modern hydro-electric developments as compared with the earlier schemes of fifty years ago. The use and advantages of bright colour treatment for the interior of Power Stations were also emphasised. Examples were shown of British and Continental practice, including a full description of the Owen Falls Scheme, the proposed High Dam at Aswan and the Kariba Hydro-Electric Project on the Zambesi. The talk was given in the East African Railways lecture room before an interested audience.

Following the lecture a meeting was held with Committee Members of the East African Section, including the Chairman, Mr. R. A. Sutcliffe ; the Honorary Secretary, Mr. L. A. Spooner (Associate-Member) ; Mr. R. A. Cabel and Mr. J. A. K. Schou (Associate-Members). A full discussion took place on various points of special concern to local members and matters affecting the future development of the East African Section. Thereafter a dinner was held in Torrs Hotel at which about 30 of the local Structural members and their friends were present. The President in his speech pointed out that this was the first occasion on which a President had been in Kenya and Uganda. He stressed the necessity of bringing before the public the important work which was being done by Structural Engineers in Africa with a view to enhancing the prestige of the Institution and its members.

On the following afternoon, 8th August, the President and his wife left Nairobi by air for Salisbury, being seen off at the Airport by Mr. Sutcliffe and Mr. Spooner. On arrival at Salisbury Airport in the evening of the 8th August, they were met by Dr. Henry Olivier, C.M.G., a fellow Director with the President of the firm of Gibb, Coyne, Sogei (Kariba) (Pvt.) Ltd., who are dealing with the consulting work for the great Kariba Hydro-Electric project. Also at the Airport was Mr. K. G. Stevens (Member) the Institution representative for the Federation of Rhodesia and Nyasaland and also Vice-President of the Rhodesian Institution of Engineers. Special mention must be made of the attention and hospitality extended to the President and his wife during their stay in Rhodesia by Mr. and Mrs. Stevens, who in addition accompanied them on their visits to Kariba, Victoria Falls, Bulawayo and Vumba. Mr. Stevens devoted the whole of his time during the President's stay in Rhodesia to assisting him in every way possible ; the help given is recorded with gratitude by the President.

In Salisbury the President was taken by Mr. Stevens to the Polytechnic College and was shown round by the Principal, Mr. Davies and Mr. Mackenzie, the lecturer on Structural Engineering. On the evening of 9th August the Dinner of members resident in the Salisbury area was held, under the Chairman, Mr. Stevens, in Meikles Hotel, at which about 30 were present, including a lady member, Mrs. M. Chatterton (Member).

One of the principal guests was Mr. Duncan L. Anderson (Member), Chairman of the Federal Power Board dealing with the Kariba Project. The President spoke of his great pleasure in being the first President to visit Rhodesia and referred to the outstanding examples of modern architectural and structural design in the new public buildings being erected in Salisbury. He also made reference to the Kariba project and expressed his pleasure that Mr. Duncan Anderson, Chairman of the Board, had been able to attend, not only as a distinguished guest, but also as a Member of the Institution. Several matters of interest were raised by members present and discussed by the President.

On 10th August the private 7-seater plane belonging to the President's Firm took off for Kariba with Mr. and Mrs. Stevens also on board, as well as the President and his wife and Dr. Henry Olivier, the Resident Director of Gibb, Coyne, Sogei (Kariba) (Pvt.) Ltd. The Kariba Hydro-Electric Project promoted by the Federal Power Board of Rhodesia is the largest engineering work in progress in Africa and one of the greatest hydro electric schemes ever constructed. It involves the construction of a large arch dam 420 ft. high and 1,900 ft. long in the Kariba gorge some 240 miles north west of Salisbury. The reservoir so formed will be the largest man made lake in the world with a length of 140 miles and a surface area of 2,000 square miles. It will be about 4½ times greater than that formed by the Hoover Dam in America. Housing has been provided at the site for 1,500 Europeans and 8,500 Africans and over 125 miles of access roads have been formed for construction purposes. About 1,400,000 cubic yards of concrete will be needed for the dam and 1,700,000 cubic yards in the entire project. The ultimate installed plant will total 1,200,000 kW in two underground Power Stations; the first installation will be five sets each of 100,000 kW. Power is to be available by mid 1960 and to achieve this very fast construction programme special efforts are being made by the Italian Civil Engineering Contractors, Impresit (Kariba) (Pvt.) Ltd. The cost of the scheme is estimated at £80 million. The works impressed the President and his party by their magnitude and by the manner in which the European and native labour are tackling their formidable task.

After the inspection of the Kariba works the party left by air on 11th August for Victoria Falls some 225 miles to the south west. Here the river and weather were such as to show this world famous spectacle under both colourful and impressive conditions. After staying the night at the attractive Victoria Falls Hotel, the party left early on the morning of 12th August for a flight of 250 miles to Bulawayo. At this place arrangements were made for the President to meet local members and with Mr. Stevens in the chair an enjoyable lunch was held in the Connaught Rooms. Among the dozen members of the Institution who were present mention must be made of Mrs. M. T. Lindsay (Associate-Member) and Mr. Joseph Swindells (Member) of Gwelo who, in order to be present both at the Salisbury and at the Bulawayo meetings, covered a total distance of over 500 miles by road. Back by air to Salisbury on that evening the next day was spent in visiting a tobacco auction, attending a lunch at the Salisbury Club with Mr. Stevens, and visiting the McIlwaine Dam, a modern earthen dam. The reservoir so formed provides Salisbury with water and also gives some excellent boating. In the evening of 13th August, the President gave his lecture in the Polytechnic College at which Mr. Stevens took the chair. The lecture was well attended. On the following day the party left by road for Vumba about 180 miles distant via Rusape and Umtali. The Leopards Rock Hotel at Vumba is beautifully situated in the mountains with magnificent scenery.

On 16th August, the President and his wife, with Mr. Robert Fitt (Member), one of his London Partners who was in Salisbury on business at this time, and accompanied by Mr. Stevens, paid a visit to the University College of Rhodesia and Nyasaland officially opened in March, 1957. They were shown over the magnificent new buildings and equally impressive grounds by the Principal, Dr. Walter Adams, C.M.G., who explained the aims of this new University recently visited by its President, the Queen Mother, and where equal opportunities exist for European and African graduates. The afternoon of this day saw the departure of the President and his wife by air to Johannesburg after a most memorable stay in Rhodesia. This was the termination of the arrangements for the President's tour which had been made so far by his Firms in Nairobi and Salisbury in consultation with the Institution's local representatives. Thereafter the arrangements fell solely on the Union of South Africa Branch whose representatives and members discharged these duties with efficiency, extreme hospitality and warm hearted friendship wherever the President was taken.

On arrival at the Johannesburg Airport Mr. and Mrs. Guthrie Brown were met and welcomed by Mr. J. Gordon Hay (Member) Chairman of the Branch, and Mrs. Hay and by Mr. T. Breslin (Member) Vice-President and immediate past Chairman, and Mrs. Breslin.

The week's stay in Johannesburg was possibly the most strenuous of the tour and the members of the Johannesburg section who had been delegated to entertain the President and his wife carried out their task with the greatest possible pleasure. The hospitality extended was overwhelming in its kindness. It is not possible to detail all that was included during the period spent in Johannesburg, but mention must be made of the visit to Pretoria on 19th August with Mr. C. A. Rigby (Member) and his wife to see the magnificent setting of the Government Administrative Buildings together with the beautiful grounds. While in Pretoria, a visit was made to the National Building Research Institute where the Principal, Dr. N. Stutterheim, took the party through the Institute and showed them the principal items of research at present in progress.

On the afternoon of the 19th August a Committee Meeting of the Union of South Africa Branch, under the Chairmanship of Mr. Gordon Hay, took place in the Carlton Hotel, at which the President was invited to attend. In addition to Mr. Gordon Hay (Chairman) there were also present Mr. T. Breslin, Mr. F. F. Binswanger, Mr. E. B. Kretzschmar, Mr. G. C. Lillicrap, Mr. G. S. Laing, Mr. E. L. Margo, Prof. A. J. Ockleston, Mr. C. A. Rigby, Mr. F. B. Thompson and Mr. A. E. Tait, Branch Hon. Secretary.

At this meeting, the President read two letters from Major Maitland, the first on behalf of the Council requesting that the Branch should nominate one of the members to visit Britain, during the Jubilee Celebrations in October, 1958, to represent the Union of South Africa Branch, and the second, announcing that the Council had decided to present Mr. Tait with a gold watch as an appreciation of his 21 years of service as Honorary Secretary to the Branch. The Committee expressed their grateful thanks for the Council's action and unanimously agreed that Mr. Tait should be nominated as their representative. Various other matters concerning the operation of the Branch,

as well as items of general interest, were discussed in detail. The President expressed his pleasure at being present and promised to have all the matters raised by the Branch placed before the Secretary and Council on his return. In addition to Mr. Tait, it should be noted that Mr. G. M. Frost (Past Chairman) has also been a member of the Branch Committee for the past 21 years. In the evening, a dinner arranged by Mr. and Mrs. T. Breslin took place in the beautiful surroundings of the Country Club.

On the 20th August, accompanied by Mr. and Mrs. G. M. Frost they visited the Taaibos and Highveld Power Stations. The former of 480,000 kW capacity has been in operation for a few years, while the latter, which is nearby, is at present under construction. On the following day, accompanied by Mr. and Mrs. T. Breslin, an inspection was made of the Vaal Dam, which is situated some 50 miles from Johannesburg. Following this, a visit was made to the Zuikerbosch Pumping Station near Vereeniging where water from the Vaal is treated and purified for use in Johannesburg. Both these visits were of special interest. On the evening of 20th August, the President and his wife were the guests at the dinner of the Johannesburg Section of the Branch. This was a most enjoyable and light-hearted function at which about 170 people were present. The ladies introduced colour and gaiety into the proceedings. The toast of the Institution was proposed by Mr. Breslin and the President replied in that humorous vein which has been so much appreciated by members during his visits to the Branches in the United Kingdom.

On the evening of 21st August, the President gave his lecture in the University before a large audience. On the following day, as a complete change from visits to works of technical interest, the President and his wife were taken by Mr. and Mrs. Binswanger and two representatives of the non-European Affairs Department to visit the native quarters and see the schools for native children and new housing for Africans at Orlando East, Pimville, Moroka and elsewhere. The visit was most interesting and instructive showing the special attention being given to educate the young children and the efforts to improve the housing conditions for the Africans in Johannesburg.

As the climax to the visit to Johannesburg, the Mayor and Mayoress, Mr. and Mrs. Max Goodman, gave a Cocktail Party in the Town Hall on the evening of 22nd August at which a large number of Structural Engineers and other distinguished guests, including Dr. Kanthack, a well known Consulting Engineer, were present. The Mayor made a gracious speech expressing his appreciation that the President of the Institution of Structural Engineers had been in Johannesburg for a few days and wished every success to the Institution and its members. The President replied saying how much he had enjoyed the visit and how the friendly hospitality received had been overwhelming and unforgettable.

On the 23rd August the President and his wife left by afternoon train for Durban. They were seen off by Mr. and Mrs. Hay, Mr. and Mrs. Breslin, Mr. and Mrs. Tait, Mr. and Mrs. Lillicrap and the Assistant Secretary, all of whom, with many others, had done so much to make the visit to Johannesburg both pleasant and memorable. On arrival at Durban on the following morning, after a 17-hour journey, the President and his wife were met by Mr. J. C. Panton (Associate-Member) Hon. Secretary of the Natal Section of the Branch, and Mrs. Panton and by Mr. E. G. Bennett (Associate-Member) and Mrs. Bennett, who drove them to their Hotel on the sea front. As at Johannesburg, the friendship and hospitality extended by members in Durban to the President and his wife, were outstanding. On the evening of their arrival a Cocktail Party at the home of Mr. H. M. Irving (Member) and Mrs. Irving, enabled them to become acquainted with local members and friends.

A visit was made with Mr. and Mrs. L. A. Gaitskell and Mr. and Mrs. E. G. Bennett on Sunday, 25th August, through the sugar growing district north of Durban to the Valley of a Thousand Hills and thence to the Nagle Dam on the Umgeni River. It is of interest to note that Mr. Leslie Turner and the Secretary were present at the official opening on 18th April, 1950, of this large dam for which Mr. Irving was the Resident Engineer. Other interesting visits while at Durban were to the Natal Technical College, where Mr. J. C. Dickson (Associate) and Mr. J. F. B. Brown (Member) showed the President and his wife around the various sections. Later the President visited the University, beautifully situated on the heights overlooking Durban. Here he was shown round by Professor J. R. Daymond (Associate-Member) and met the Principal, Dr. Malherbe. On the evening of 26th August, the President gave his lecture in the University at Durban before a large and appreciative audience.

On 27th August a visit was arranged by Mr. Jervis of the Roberts Construction Company to see construction on the new prestressed concrete bridge across the River Tugela about 70 miles north of Durban. The President was accompanied by Messrs. Panton, Bennett and Irving. The bridge is an interesting structure of 7 spans each of 200 ft., the whole being fully continuous and all prestressed. The foundations for the piers are being taken to rock in caissons. Construction was in full progress during the visit, a special effort being required to have the remaining foundations in the river fully secured before the October floods. During the day Professor Daymond brought a party of engineering graduates to the site to see construction in progress. In the evening a most interesting day was rounded off by a dinner given by Mr. and Mrs. Jervis.

On 28th August, following a visit to a Rayon Factory south of Durban, operated by British and Italian interests, the dinner of the Natal Section of the Branch took place at the Marine Hotel, among the distinguished guests being Dr. Malherbe. The toast of the Institution was proposed by Mr. E. G. Bennett, Chairman, and replied to by the President, who expressed his pleasure in meeting so many members of the Natal Section of the Union of South Africa Branch, and thanked them for making the visit such a pleasant one.

On 29th August, the President and his wife embarked on the " Pretoria Castle " which was to be their home for the remainder of the tour in Africa before leaving Cape Town on 6th September.

Their stay in Durban was made memorable and enjoyable by the friendship and hospitality extended to them by local members, special acknowledgement being due to Mr. and Mrs. E. G. Bennett, Mr. and Mrs. H. M. Irving, Mr. and Mrs. L. A. Gaitskell, as well as to Mr. J. C. Panton, Hon. Secretary and Mrs. Panton. Nothing was too much for these members to give to the entertainment of the President and his wife.

On 30th August, the " Pretoria Castle " docked at East London. Mr. and Mrs. Guthrie Brown were met by Mr. A. Bank (Graduate) the only member resident at present in the district. Mr. and Mrs. Bank devoted the whole time of the visitors' stay in East London to showing them the most interesting scenery in the neighbourhood, including one of the largest pineapple

farms. Mr. Bank also arranged a meeting with the Mayor of East London, who expressed pleasure at the visit of the President and explained certain of the local problems he had to contend with. They left East London with many happy memories of the hospitality of Mr. and Mrs. Bank.

On the 31st August the vessel reached Port Elizabeth and here they were met by Mr. D. D. Thomson (Associate-Member) and his wife. A tour of the city and its surroundings was arranged to enable the President to appreciate the industrial and other developments in progress. A visit to the Port Elizabeth Snake Pit to see the poison being extracted from snakes in order to prepare an antidote to snake bite was of great interest. Mr. Thomson arranged a lunch party at which local Institution members could meet the President, these including Mr. W. S. Cragg (Associate-Member) and Mrs. Cragg, Mr. C. J. Harris (Graduate) and Mrs. Harris, Mr. E. B. Wardle (Associate-Member) and Mrs. Wardle. The President thanked those present for their kind hospitality and stressed the importance of close liaison with the Johannesburg section, especially in connection with the Jubilee Celebrations in 1958.

On Monday, 2nd September, the " Pretoria Castle " arrived in Cape Town for a four days' stay there. Into this short period the members at Cape Town crammed an amount of friendly hospitality, sightseeing and entertainment which equalled any experienced on the tour and which was greatly appreciated by the President and his wife. The beauties of Cape Town and its surroundings were shown in full in the time available, and the weather was perfect. They have unforgettable memories of the beach scenes around the Peninsula, the beautiful Kirstenbosch Gardens, the wild flower reserve at Paarl and not least, the unique view of Cape Town by night from Signal Hill (1,147 feet) with the myriads of twinkling lights below. To crowd all these visits into four days required careful organisation by the Honorary Secretary, Mr. R. F. Norris (Associate-Member) and other local members. Special mention must be made of Mr. and Mrs. R. F. Norris, Mr. I. Gilinsky (Associate-Member) and Mrs. Gilinsky, Mr. A. C. Liebenberg (Associate-Member) and Mrs. Liebenberg, Mr. D. MacDonald and Mrs. MacDonald, Mr. D. A. H. Hill (Associate-Member) and Mrs. Hill, Mr. A. Downie (Associate-Member), Mr. H. Evans (Associate-Member) and Mrs. Evans, Mr. S. K. Jordan (Member) and Mrs. Jordan. They all devoted their time and provided the necessary transport to take the President and his wife to the many places of interest around Cape Town.

One outstanding visit was arranged by Mr. S. S. Morris, M.I.C.E., City Engineer of Cape Town. Although not a member of the Institution, he took a keen interest in the arrangements for the President's visit and organised an inspection of the dams at Steenbras and Wemmershoek. The former was a conventional gravity dam which was strengthened and heightened 6½ ft. by Mr. Morris in consultation with M. Coyne by means of prestressed cables anchored into the rock under the dam. This enabled the increased demand for water for Cape Town to be met with the least delay. The attention given to the maintenance of the dam and the landscape treatment of the surrounding areas and especially of the rock gardens in the ravine immediately below the dam are outstanding.

The Wemmersheok dam is a large earth embankment dam constructed under the direction of the City Engineer by George Wimpey & Co. Ltd. The final tidying up and completion of the work is now in progress. The dam itself is an outstanding engineering work and measures 1,700 ft. long by 180 ft. high.

A Cocktail Party on the evening of 3rd September gave the President the opportunity of meeting local members and their wives as well as representatives of other Institutions.

The President's lecture was given in Cape Town University on the evening of 5th September before a large audience. Mr. R. Stubbs (Member) was in the chair. Mr. Morris, City Engineer, proposed the vote of thanks at the close of the lecture.

This was the termination of the President's visit as he and his wife left by the " Pretoria Castle " on the following afternoon. They held a farewell lunch on the ship which was attended by the various local members and their wives who had made the visit so memorable, and also Mr. and Mrs. S. S. Morris.

The conclusions to be reached from the President's visit to Africa are that members in Africa greatly value a visit from the President of the Institution. This was emphasised on many occasions and the warm hearted hospitality extended to the President and his wife was confirmation of this. It was stressed that Presidential visits at closer intervals would be greatly welcomed and the President promised to bring to the notice of the Council the desirability of establishing five years as the maximum interval between Presidential visits. Many matters of interest were discussed and the special points of view of members in Africa were brought clearly to the notice of the President, who promised that these would be carefully considered by the Council.

The outstanding impressions of the tour were the flourishing conditions in the various towns visited with large commercial buildings springing up from Nairobi in the North to Cape Town in the South. All this industrial activity was producing buildings of outstanding architectural merit and Structural Engineers were doing first class work in the designs of these very tall structures.

Another notable feature was the magnificent modern road system being developed in the Union which could stand comparison with any other European country and which is far in advance of the road systems in Kenya or Rhodesia.

In interviews with the Press at Nairobi, Johannesburg and Durban, the President emphasised the important work being done by the members of the Institution in Africa and the high prestige value in belonging to this major Institution. In his speeches to members at the various dinners, the President stressed that members must make the public more aware of the work they were doing and exert themselves to publicise the work of Structural Engineers. The Jubilee Celebrations to be carried out in Africa next year with banquets in the various cities will give local sections an excellent opportunity to bring the Institution and its members before the public.

The visit of the President and his wife was made memorable by the warm hearted hospitality which was extended to them from Uganda to the Cape. The kindness shown to them was unforgettable. The President's tour has indicated how greatly the Institution of Structural Engineers is respected in Africa and how much the members there appreciate a visit from the President. It is evident that a periodic visit by a President to Africa must be looked on as an essential requirement in the future.

The Effects of the Wheel Tread Profiles and other factors on the Long Travel Motion of Gantry Cranes

By P. M. Worthington, B.Sc.(Eng.), A.M.I.C.E.

Synopsis

This paper describes a mathematical and experimental investigation into the behaviour of gantry cranes when long travelling. The work was started because of the severe wear suffered by the crane wheel flanges and the gantry rails in a number of heavy engineering works. Cranes designed with either cylindrical or conical tread wheels are in common use, and in either case a pair of wheels may or may not be made to rotate at identical speeds by means of a cross-shaft. These systems are analysed and their faults discussed. Axial float of the wheels in their bearings and the tread widths of wheels are also discussed.

One method of avoiding flange wear is to use horizontally acting guide rollers, and the paper gives the theories of spring loaded and rigid guide rollers. A new method of overcoming flange wear is described, and this consists of wheels having profiles of more complex shape. The advantages and disadvantages of the system are put forward. Finally, conclusions are drawn and recommendations made for the design of wheel and shaft systems.

All the theory has been checked, and some additional information obtained, by means of a model crane and track.

Introduction

This mathematical and experimental study of the behaviour of gantry cranes when long travelling was started in an attempt to find improvements for the cranes at Abbey Works. There, as in other works, the skewing of a crane makes the flanges of its wheels sometimes bind against the rails, thus causing considerable wear of both wheels and rails. The cost of maintenance is high, and in addition there is considerable inconvenience when wheels or rails have to be renewed. This fault is not confined to a few particular cranes, nor indeed to a few particular works; but generally occurs whenever a crane is required to travel over considerable distances. The behaviour of a crane depends upon a number of things such as the profiles of the wheel treads and positions of the connecting shafts. These things have been discussed by many authors, and the behaviour of cranes with ordinary conical wheels is now well understood.* Broadly, there are two systems in common use at present: cranes where all the wheels have cylindrical treads, and cranes having at least one pair of conical tread wheels which are made to rotate at identical speeds by means of a shaft. These two systems have entirely different characteristics, and both have some advantages and some disadvantages. For this reason the old argument between their relative merits will never be resolved. One alternative system described in this paper involves the use of spring loaded guide rollers. Although guide rollers have already been used in Germany, they are by no means common practice yet. The other alternative system involves the use of wheels with treads of varying slope.

Many other suggestions to the problem have been put forward. One is that the wheels on each side of the gantry should be independently driven by separate electric motors, the speeds of which are controlled automatically by feelers which keep contact with the rails. Another suggestion is that the crane should have a rack and pinion system. Most of these systems, however, have the disadvantage of being either costly, or liable to breakdown.

It is often suggested that the wear of crane wheel flanges is due to the mal-alignment of the rails and not to the crane itself. Of course, it is true to say that the operation of a crane is worse on a badly aligned gantry than on a correct one, but in the Author's experience the design and construction of the crane is usually by far the more important factor. It will be seen from this paper how a crane may behave badly on a perfect track, and it is the study of this sort of behaviour with which this paper is mainly concerned.

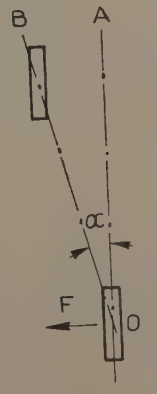

Fig. 1

Theory of Creep of Rolling Wheels

Suppose a wheel is rolling in the direction OA on a horizontal plane, as shown in Fig. 1. Let the wheel

* *A list of papers on the subject is given in Appendix II.*

load be W, and let there be an applied transverse force F, thus causing a friction force F between the wheel and the plane. If F/W is zero there is pure rolling and the wheel travels straight along OA, and if F/W is equal to the coefficient of friction the wheel slips sideways. But if F/W is between zero and the coefficient of friction, the wheel travels along a line OB at some small angle α to the plane of the wheel. This is due to the elastic strain of the surfaces in contact. The angle α is called the lateral creepage; and the coefficient of lateral creepage, μ_1, may be defined by the equation

$$F = W\mu_1\alpha \quad . \quad . \quad . \quad . \quad (1)$$

It has been shown experimentally that, within certain limits, μ_1 is constant for any particular wheel and surface, and is independent of W and α.*

Similarly, if the force F is acting along OA there will be a longitudinal slip of the wheel along OA. Thus, the distance travelled by the wheel is different from the circumference multiplied by the number of revolutions. The ratio of slip to distance travelled is known as the longitudinal creepage denoted here by β. The coefficient of longitudinal creepage, μ_2, is defined by the equation

$$F = W\mu_2\beta \quad . \quad . \quad . \quad . \quad (2)$$

It has been shown experimentally that the coefficients of lateral and longitudinal creepage are identical, and for this reason both will henceforth be denoted by the symbol μ.†

Cylindrical Tread Systems

Crane with two shafts and two pairs of wheels

First consider an accurately built crane having two shafts and two pairs of wheels as shown in Fig. 2. It

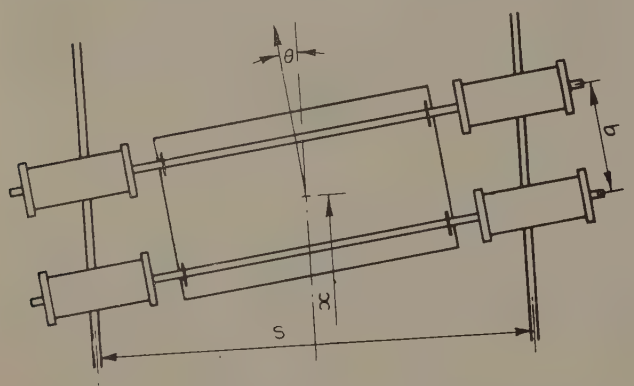

Fig. 2

will be assumed that there is no float in the axle bearings but that the tread width of the wheels is greater than the width of the rails. Let S be the span of the gantry, b the wheel base, θ the angle of skew and x the distance travelled by the crane from a given point.

If the crane has an initial skewness θ_0, it will run straight and free in a direction at right-angles to its own body until the flanges of the leading wheels come into contact with the rails. To find the subsequent motion of the crane, take moments of the creepage forces about the mid-point of the leading shaft. First, assuming the crane to be travelling in the direction of the rails but with it skewness remaining unchanged, there is a moment $2\mu W\theta b$ due to the transverse creepage of the rear wheels. Also, if the crane is rotating about the mid-point of the leading shaft there is a moment $2\mu Wb^2\frac{d\theta}{dx}$ due to the transverse creepage on the rear wheels, and a moment $4\mu W\left(\frac{S}{2}\right)^2\frac{d\theta}{dx}$ due to the longitudinal creepage on all wheels. Adding these moments together and equating to zero (since there can be no resulting moment on the crane) the equation

$$2\mu W\left(\theta + b\frac{d\theta}{dx}\right)b + 4\mu W\left(\frac{S}{2}\right)^2\frac{d\theta}{dx} = 0$$

is obtained. This can be simplified to

$$\left(\frac{S^2}{2} + b^2\right)\frac{d\theta}{dx} + b\theta = 0 \quad . \quad . \quad (3)$$

the solution of which can be written

$$\theta = Ae^{-px} \quad . \quad . \quad . \quad . \quad (4)$$

where

$$p = \frac{2b}{S^2 + 2b^2}. \quad . \quad . \quad . \quad (5)$$

A is an arbitrary constant which depends on the starting condition.

Equation (4) shows that, as the crane proceeds along the track, the skewness tends asymptotically to zero. If the crane runs in one direction until the skewness is reduced to θ_1 and then reverses, it will run straight and free at an angle θ_1 for a distance

$$\frac{t-a}{\theta_1} - b.$$

The flanges of the leading wheels will then bind against the rails and the skewness will continue to reduce. Fig. 3 illustrates this motion, the skewness of the crane being represented by short lines drawn across the curve.

Crane with one shaft and two pairs of wheels

If the crane has two pairs of wheels, only one pair of which is connected by a shaft, the other pair being free to rotate independently, Equation (3) becomes

$$\left(\frac{S^2}{4} + b^2\right)\frac{d\theta}{dx} + b\theta = 0 \quad . \quad . \quad (6)$$

the solution of which is

$$\theta = Ae^{-px} \quad . \quad . \quad . \quad . \quad (7)$$

where

$$p = \frac{4b}{S^2 + 4b^2}. \quad . \quad . \quad . \quad (8)$$

* "*Some Experiments on the Lateral Oscillation of Railway Vehicles*," by R. D. Davies, *Journal of the Institution of Civil Engineers, Vol. II*, 1938-9, *Page* 224.

† *A summary of notation is given in Appendix I.*

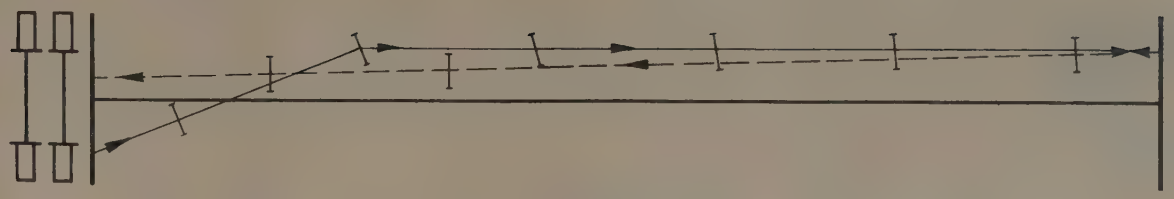

Fig. 3

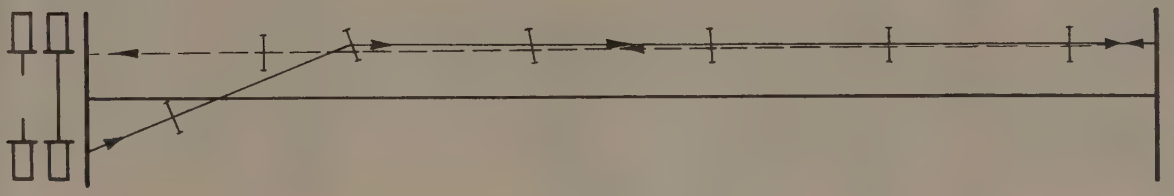

Fig. 4

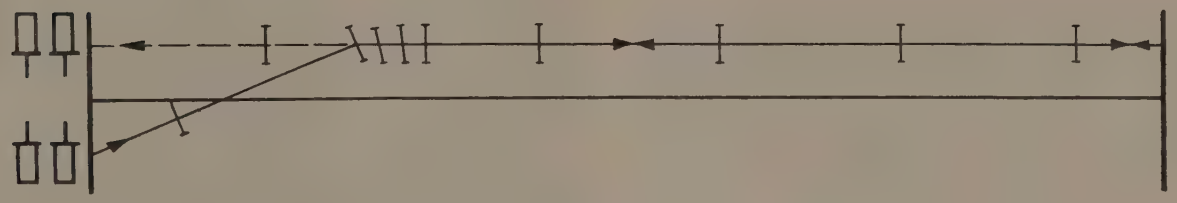

Fig. 5

Hence, in this case the skewness is reduced more quickly than that of a crane with both pairs of wheels connected. This can be seen by comparing Fig. 4 with Fig. 3.

Crane with no shaft and two pairs of wheels

Consider now the case of a crane having two pairs of wheels but no shaft, so that each wheel is free to rotate independently. It will be assumed that at least one wheel each end of the crane is driven by a separate motor, and that the motors each end of the crane have equal torques. Equation (3) becomes

$$b\frac{d\theta}{dx} + \theta = 0 \quad . \quad . \quad . \quad . \quad (9)$$

the solution of which may be written

$$\theta = Ae^{-\frac{x}{b}} \quad . \quad . \quad . \quad . \quad (10)$$

Hence, in this case the skewness is reduced very much more quickly than that of a crane with either one or two shafts. Its motion is illustrated in Fig. 5.

An idea of the relative speeds of correcting can be obtained by substituting some figures in the above formulae. For example, taking $S/b = 5$, a crane with one shaft has to travel 7.25 times as far to reduce the skewness to the same extent as a crane with no shaft. A crane with two shafts has to travel 13.5 times as far as a crane with no shaft.

It is, of course, an advantage that a crane should correct a skew angle quickly, but on the other hand there are disadvantages which will be discussed later.

The effect of axial float

It was assumed in the foregoing theory that there was no axial float in the axle bearings; but now consider the case when each front wheel is allowed an axial float $f_1/2$, and each rear wheel $f_2/2$, each side of its true and mean position. The arrangement is illustrated in Fig. 6. For the first part of this discussion

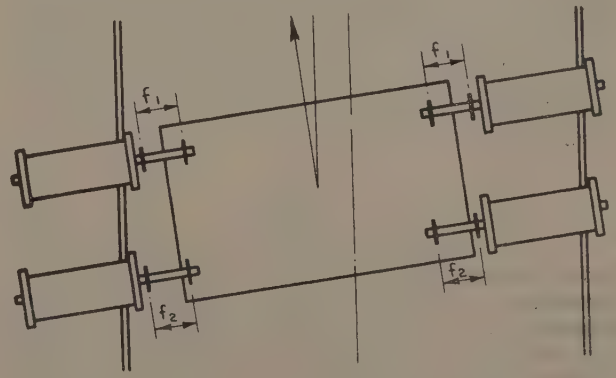

Fig. 6

it makes no difference whether there are shafts or not.

If the initial skewness is greater than $(f_1 + f_2)/2b$ the crane will correct as before until

$$\theta = \frac{f_1 + f_2}{2b} \quad . \quad . \quad . \quad . \quad (11)$$

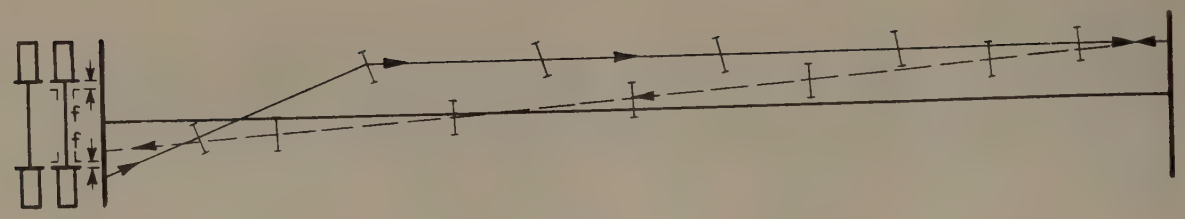

Fig. 7

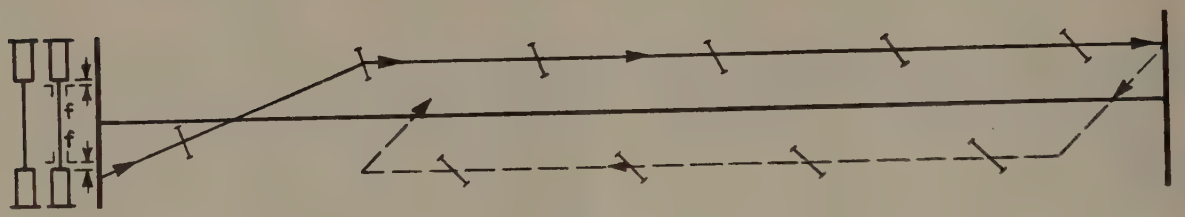

Fig. 8

and then, except for a minor effect to be described later, there is no further correction although the flanges of the wheels continue to bind. If the initial skewness lies within the range $+(f_1+f_2)/2b$ to $-(f_1+f_2)/2b$ the skewness of the crane is in neutral equilibrium and there is no tendency for it to change. In the case of a crane with no cross shaft, the slightest moment (about a vertical axis) applied to the crane will alter the angle of skewness within this range. If the motor on one end of the crane is even slightly more powerful than that on the other, the one end will advance until the skewness is given by Equation (11), and then the crane will continue to bind against the rails.

For these reasons float in the axle bearings is not desirable and should always be avoided in cylindrical tread systems.

The results of tests with the model crane having two pairs of wheels and two shafts are illustrated in Figs. 7 and 8, and an interesting effect is shown. According to the theory given above, the skewness of the crane should remain constant, whatever the initial angle, provided that θ_0 lies between plus and minus $(f_1+f_2)2b$. In fact, it is seen that when the flanges are inside the track, the crane has a tendency to straighten, and when the flanges are outside the skewness increases until

$$\theta = \frac{f_1+f_2}{2b}. \quad . \quad . \quad . \quad . \quad (12)$$

This is because, when a flange is binding, the effective diameter of the wheel is a little larger than the tread diameter. Thus, when a pair of wheels is connected by a shaft, the wheel with the binding flange tends to travel faster along the track, so steering the crane.

In a crane having no shaft, the opposite happens. When a pair of wheels is not connected with a shaft, the effect of the increasing effective diameter is completely lost, but another effect of opposite sign is brought in. When the flange of a wheel on one end of the crane is binding, a considerable retarding force is introduced, and the other end of the crane tends to move faster.

Thus, when all wheels are connected with shafts there is an advantage in having the flanges on the insides of the wheels; but when there are no shafts there is an advantage in having the flanges on the outsides. In an intermediate case when some pairs of wheels are connected and some are not, the two forces compete. The Author is unable either from theory or from tests with the model to give a general guide as to whether it is better to have the flanges inside or outside on such cranes. It might seem from the theory that the flanges of connected wheels should be inside and the flanges of unconnected wheels outside on the same crane. This would be undesirable, however, since the span of the gantry can vary in practice, and on such a crane this would give the effects of mal-alignment of the wheels.

The effect of mal-alignment of the wheels

Now consider a crane having two pairs of wheels and two shafts, but in this case having the wheels incorrectly aligned as shown in Fig. 9. The axes of

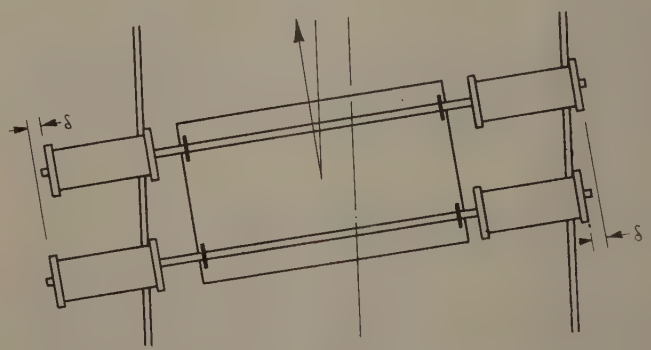

Fig. 9

all four wheels are parallel but the rear wheels have an axial displacement δ relative to the front wheels.

If the initial skewness exceeds δ/b the flanges of the front wheels bind first and the crane then moves according to Equation (4) until the flanges of the rear wheels also bind. This happens when $\theta = \delta/b$. If the initial skewness is less than δ/b the flanges of the rear wheels bind first. In this case it is possible to find the subsequent motion of the crane by taking

moments of the creepage forces about the mid-point of the rear shaft. Thus

$$2\mu W\left(\theta - b\frac{d\theta}{dx}\right)b - 4\mu W\left(\frac{S}{2}\right)^2\frac{d\theta}{dx} = 0$$

or

$$\left(\frac{S^2}{2} + b^2\right)\frac{d\theta}{dx} = b\theta \quad . \quad . \quad . \quad (13)$$

the solution of which may be written

$$\theta = Ae^{px} \quad . \quad . \quad . \quad . \quad (14)$$

where

$$p = \frac{2b}{S^2 + 2b^2} \quad . \quad . \quad . \quad . \quad (15)$$

This shows that the skewness increases as the crane travels, and the increase continues until the flanges of the front wheels bind in addition to the flanges of the rear wheels. The skewness given by

$$\theta = \frac{\delta}{b} \quad . \quad . \quad . \quad . \quad (16)$$

is therefore a stable skewness, and after the crane has any small disturbance the skewness returns to this value. When the crane reverses it will run freely for a distance

$$\frac{(t-a)}{\theta}$$

when the flanges on the opposite sides of the wheels start to bind. Hence, if a crane with an error δ is only required to operate over a distance

$$\frac{(t-a)b}{\delta},$$

the flanges will not bind repeatedly. It is only when the crane is required to operate over a greater length of track that repeated binding occurs. These points are illustrated in Fig. 10.

While the crane is running skew-wise along the track, the lateral creeping force in each wheel is reacted by a force between the flange of the wheel and the side of the rail. This force is given by Equation (1).

If the crane shown in Fig. 9 were to be skewed in the opposite direction, then whatever the angle of skew the front wheel would bind first. Then according to Equation (4) the skewness would tend asymptotically to zero as is shown in Fig. 11. If the crane were reversed when the angle of skewness had reduced to θ_1, the crane would run straight and free for a distance

$$\frac{(t-a-\delta)}{\theta_1} - b$$

when the flanges of the front wheels would bind again and the skewness continue to correct. The position of no skewness, however, is a position of unstable equilibrium and the only position of stable equilibrium is that given by Equation (16).

The behaviour of cranes with one shaft or no shafts is identical with the behaviour of cranes with two shafts except that the rate of moving into the stable position of skewness is greater. The angle of stable skewness is the same in each case, and so is the intensity of grinding.

The effect of different motor torques on cranes without shafts

The case of an accurately built crane having two pairs of wheels and no shafts will now be re-considered, this time taking into account the effect of different tractive forces on the two ends of the crane. It has already been shown that there is a correcting moment on the crane due to the transverse creepage of the rear wheels of $2\mu W\theta b$. Hence, if the difference between the two tractive forces, P_1 and P_2, is given by

$$P_1 - P_2 = \frac{4\mu W\theta b}{S} \quad . \quad . \quad . \quad (17)$$

the skewness has no tendency to correct but remains constant. If, however, $P_1 - P_2$ is greater, the angle θ will increase. To obtain an idea of the magnitude of $P_1 - P_2$ that will upset an actual crane, some values can be substituted in Equation (17). For

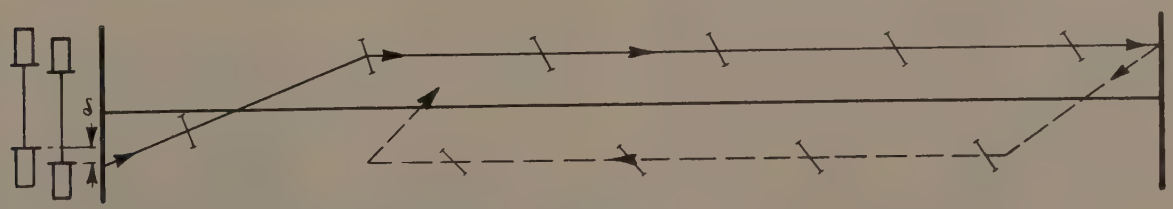

Fig. 10

Fig. 11

Fig. 12

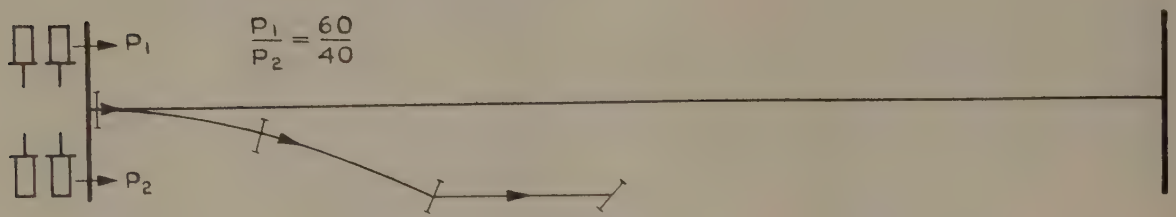

Fig. 13

example, take $S/b = 5$, and let the crane be in equilibrium at a skew angle $\theta = 1/600$ (that is, when one end leads the other by 2 inches per 100 feet of span). Then, taking μ as 155*

$$P_1 - P_2 = \frac{W}{4.8}.$$

An assumption inherent in Equation (17) is that the frictional resistances at the two ends of the crane are equal. But it has already been shown that this is not always the case, and when the flange of a wheel on one end of the crane is binding, a considerable retarding force is introduced which causes that end of the crane to move slower than the other.

Two tests with the model crane are shown in Figs. 12 and 13. Different values of the ratio $P_1{:}P_2$ were obtained by attaching the towing thread to some point other than the mid-point of the crane. Thus, to obtain the ratio $P_1{:}P_2{::}55{:}45$ the thread was attached to a point on the crane 45 per cent across the rail span. Figs. 12 and 13 give results for a crane with the flanges inside, and it was found that the crane became unstable if the ratio $P_1{:}P_2$ is greater than about 57:43. Similar experiments with the flanges outside showed that the crane continued to be stable until $P_1{:}P_2$ exceeded about 85:15 although considerable flange binding took place when the ratio exceeded 75:25. This shows the great advantage in having the flanges on the outside only in cranes without shafts.

Spring loaded guide rollers

Two pairs of spring loaded guide rollers can be introduced with great advantage whether there are shafts or not. The arrangement is shown diagrammatically in Fig. 14. It should be noticed that at least two pairs of guide rollers are required so that a correcting moment (about a vertical axis) is applied when the crane is skew, as well as a correcting lateral force being applied when the crane is laterally displaced. Otherwise the crane could travel skew-wise continuously without any means of correction.

* *This value is taken from "Some Experiments on the Lateral Oscillation of Railway Vehicles," by R. D. Davies, Journal of the Institution of Civil Engineers, Vol. II, 1938-9, Page 224.*

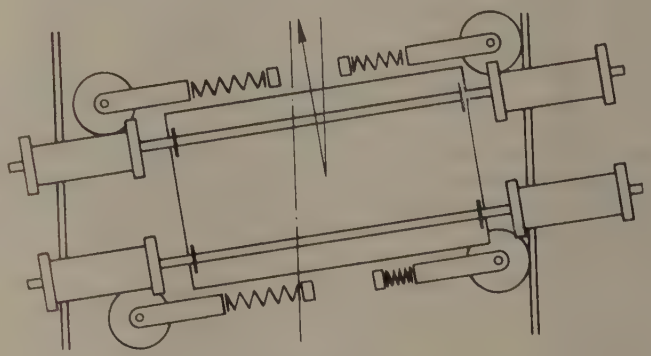

Fig. 14

Conical Wheel Systems

Crane with two shafts and two pairs of wheels

Consider a crane having two pairs of conical wheels, each pair being connected with a shaft. Let the body of the crane be rigid, and let there be no float in the bearings. The system is shown in Fig. 15.

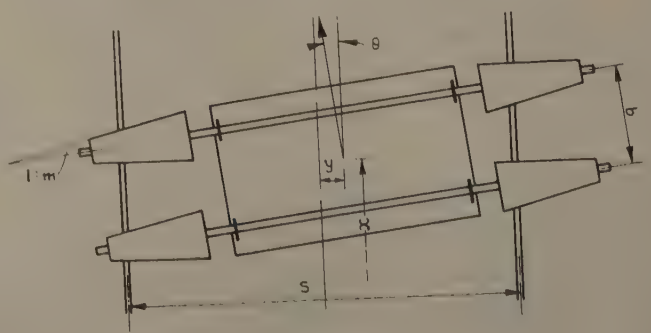

Fig. 15

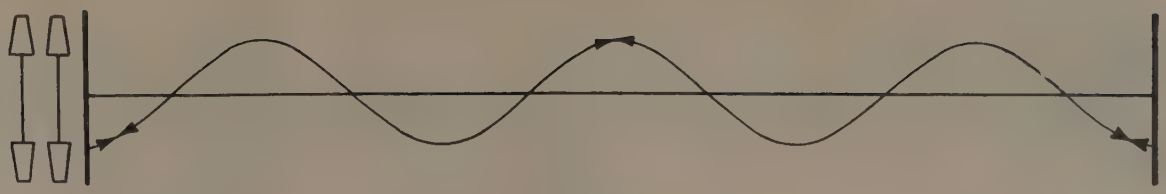

Fig. 16

The rate of lateral creepage of the front pair of wheels is

$$\frac{b}{2}\frac{d\theta}{dx}$$

which, from Equation (1), corresponds to a force on the crane of

$$2W\mu\frac{b}{2}\frac{d\theta}{dx}.$$

This, together with an equal and opposite force to the back pair of wheels, gives a couple on the crane of

$$-W\mu b^2\frac{d\theta}{dx}.$$

The rate of longitudinal creepage on the left-hand front wheel is

$$-\frac{S}{2}\frac{d\theta}{dx}+\left(y-\frac{b}{2}\theta\right)\frac{2}{mD},$$

where m is the cotangent of the coning angle of the wheel and D is its mean diameter. By Equation (2) this longitudinal creepage corresponds to a force on the crane of

$$-\frac{SW\mu}{2}\frac{d\theta}{dx}+\frac{2W\mu}{mD}\left(y-\frac{b}{2}\theta\right)$$

which, together with the forces on the other three wheels, gives a couple on the crane of

$$-S^2W\mu\frac{d\theta}{dx}+\frac{4\,W\mu S}{mD}\,y.$$

By adding the couples due to lateral and longitudinal creepage, and equating to zero, a differential equation of motion is obtained. Thus

$$\left(S^2+b^2\right)\frac{d\theta}{dx}-\frac{4S}{mD}y=0. \quad . \quad . \quad (18)$$

Another equation of motion, obtained solely from the direction of rolling, is

$$dy=-\theta dx. \quad . \quad . \quad . \quad (19)$$

Eliminating θ from these last two equations,

$$\frac{d^2y}{dx}+\frac{4}{mDS\left(1+\frac{b^2}{S^2}\right)}y=0, \quad . \quad (20)$$

is obtained, the solution of which may be written

$$y=A\sin\sqrt{\left[\frac{4}{mDS\left(1+\frac{b^2}{S^2}\right)}\right]}x, \quad . \quad . \quad (21)$$

the origin of the axis of x being chosen suitably. This shows that the system travels in a pure sine curve as shown in Fig. 16. The wave-length λ is given by

$$\lambda=\pi\sqrt{\left[mDS\left(1+\frac{b^2}{S^2}\right)\right]} \quad . \quad . \quad (22)$$

and the amplitude depends solely on the starting conditions. By eliminating y from Equations (19) and (21) the angle of skew at any point may be obtained. Thus

$$\theta=-A\sqrt{\left[\frac{4}{mDS\left(1+\frac{b^2}{S^2}\right)}\right]}\times\cos\sqrt{\left[\frac{4}{mDS\left(1+\frac{b^2}{S^2}\right)}\right]}x. \quad . \quad (23)$$

Crane with one shaft and two pairs of wheels

Now let the rear shaft of the crane shown in Fig. 15 be disconnected so that the rear wheels can rotate at different speeds. As in the crane with two shafts, the lateral creepage of the front pair of wheels is

$$\frac{b}{2}\frac{d\theta}{dx}$$

which, from Equation (1), corresponds to a force on the crane of

$$2W\mu\frac{b}{2}\frac{d\theta}{dx}.$$

This, together with an equal and opposite force to the rear pair of wheels, gives a couple on the crane of

$$-W\mu b^2\frac{d\theta}{dx}.$$

The longitudinal creepage of the left-hand front wheel is

$$-\frac{S}{2}\frac{d\theta}{dx}+\left(y-\frac{b}{2}\theta\right)\frac{2}{mD}$$

which, from Equation (2), corresponds to a force on the crane of

$$-\frac{SW\mu}{2}\frac{d\theta}{dx}+\frac{2W\mu}{mD}\left(y-\frac{b}{2}\theta\right).$$

Fig. 17

This, together with the force on the right-hand front wheel, gives a couple on the crane of

$$-\frac{S^2W\mu}{2}\frac{d\theta}{dx}+\frac{2W\mu S}{mD}\left(y-\frac{b}{2}\theta\right).$$

Adding the couples together and equating to zero a differential equation of motion of the crane is obtained. Thus

$$\left(1+2\frac{b^2}{S^2}\right)\frac{d\theta}{dx}-\frac{4}{mDS}\left(y-\frac{b}{2}\theta\right)=0. \quad . \quad (24)$$

Eliminating θ from this equation and Equation (19),

$$\left(1+2\frac{b^2}{S^2}\right)\frac{d^2y}{dx^2}+\left(\frac{2b}{mDS}\right)\frac{dy}{dx}+\left(\frac{4}{mDS}\right)y=0, \quad (25)$$

the solution of which may be written

$$y=Ae^{-px}\sin\sqrt{(q^2-p^2)}x \quad . \quad . \quad (26)$$

where

$$p=\frac{b}{mDS\left(1+2\frac{b^2}{S^2}\right)} \quad . \quad . \quad . \quad (27)$$

and

$$q=\sqrt{\left[\frac{4}{mDS\left(1+2\frac{b^2}{S^2}\right)}\right]}, \quad . \quad . \quad (28)$$

the origin of the axis of x being chosen suitably. This shows that the crane travels in a damped sine curve, the wave-length being given by

$$\lambda=\frac{2\pi}{\sqrt{(q^2-p^2)}}, \quad . \quad . \quad . \quad (29)$$

and the damping factor, ρ, being given by

$$\rho=e^{-\lambda p} \quad . \quad . \quad . \quad . \quad (30)$$

The damping factor is defined as the ratio of the amplitude at one oscillation to the amplitude one wave-length previously.

If the crane reverses, it retraces its tracks and the amplitude increases. This can be shown by making b negative in Equations (27) and (28). The damping factor becomes

$$e^{\lambda p}$$

Since the damping which occurs when the crane travels in one direction is off-set by the excitation when the crane travels in the other direction, this system has no advantage over the two shaft system shown in Fig. 15. In fact, it has a disadvantage, because if the crane has a slight disturbance and then travels backwards for a great distance its amplitude increases until the flanges rub the rail each time as it oscillates from side to side.

The motion of the crane is illustrated in Fig. 17.

It should be noticed that whether the free running rear wheels have cylindrical or conical treads makes no difference to the calculations. This is because the steering effect of conical treads does not exist unless the pair of wheels is made to rotate at the same angular speed. Hence the choice of conical or cylindrical treads for the free wheels makes no difference to the motion of the cranes. This has been confirmed with the model.

Crane with no shaft and two pairs of wheels

If neither pair of wheels is connected, the choice of cylindrical or conical treads for all wheels makes no difference to the performance of the crane. It may be said, therefore, that a crane having no shafts and two pairs of conical wheels is identical to the crane having no shafts and two pairs of cylindrical treads. The motion of this crane has already been described.

Cranes with more than two pairs of wheels

The motion of a crane having more than two pairs of wheels follows the same principles as those already described in this paper. Exact formulae for the wave-lengths, amplitudes and damping factors of some cranes having four pairs of wheels have been calculated by Diamond and Frankau.* Also, some experimental results are given in Table I.

The effect of axial float

Consider now the effect of axial float in a crane having two shafts and two pairs of conical wheels. The simplest case to discuss is when the float is so great that the natural axial movement of the shafts relative to each other is never restricted. The rear shaft does not exactly follow the front one but describes an equal sine curve slightly out of phase as shown in Fig. 18. The motion of each shaft is unaffected by the other, and the equation of its motion can therefore be found by putting $b=0$ in Equation (21), thus

$$y=A\sin\sqrt{\left(\frac{4}{mDS}\right)}x. \quad . \quad . \quad (31)$$

The wave-length is given by

$$\lambda=\pi\sqrt{(mDS)}. \quad . \quad . \quad . \quad (32)$$

* "*The Effect of Tapered Treads on the Motion of Overhead Travelling Cranes*," by E. L. Diamond and A. M. Frankau, *Proceedings of the Institution of Mechanical Engineers, Vol.* 162, 1950, *Page* 225.

Wheel System	Wave-lengths (inches) →	Wave-lengths (inches) ←	Damping factors →	Damping factors ←	Damping factors Geometric mean
	40	40	1·00 †	1·00 †	1·00 †
	40	40	0·50	2·10	1·00 †
	55	55	0·35	2·90	1·00 †
	52	52	0·55	1·80	1·00 †
	43	43	0·45	2·30	1·00 †
	42	42	1·00†	1·00†	1·00 †
	41	41	1·00†	1·00†	1·00 †
	41	38	0·35	1·25	0·65
	60	43	0·15	1·80	0·50
	49	41	0·25	1·00	0·50
	46	40	0·25	1·40	0·60
	40	40	0·65	0·65	0·65
	41	41	0·60	0·60	0·60
	54	49	0·45	1·00	0·65
	57	44	0·20	1·85	0·60
	52	41	0·40	1·00	0·65
	56	56	0·75	0·75	0·75
	27	27	0·45	1·15	0·70

TABLE I

* These wave-lengths and damping factors are not independent of the amplitude. The figures given correspond to an amplitude of the model of ± 0.05 inch.

† These damping factors are theoretically unity.

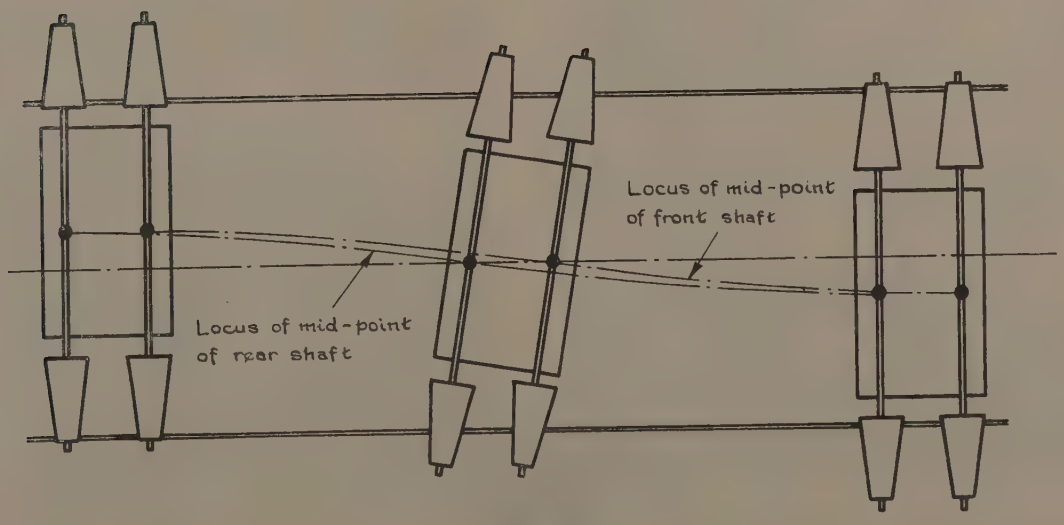

Fig. 18

Hence, the motion of the crane is the same as that when no float exists, except that the wave-length is very slightly decreased. This has no practical advantage. It may be said that there is a slight advantage in that there is no lateral creepage and therefore less wear on the treads when float is provided, but tread wear due to this cause is unimportant.

Now suppose that the amount of axial float is limited in extent, so that at times during the oscillations, the relative movement of the shafts is prevented. Davies has shown that this causes a slight damping of the sine curve, but unlike previous damped sine curves, the damping exists whichever direction the crane travels.† It is unfortunate, however, that this damping is too mild to be of practical use. It will be noted that in extreme cases when there is either no axial float or unrestricted axial float, the sine curve is not damped.

In the foregoing discussion it was assumed that a pair of wheels, although having an axial float, are kept a constant distance apart by means of the connecting shaft. If this were not done, the taper of the tread would lead each wheel to creep inwards until all the float was taken up. Thus, the effect of the float would then be eliminated.

The foregoing discussion on axial float can be summarized as follows. Float on a crane having two shafts and two pairs of conical wheels is not worth while and involves the difficulty of keeping the span between a pair of wheels constant. A much more interesting and advantageous effect happens, however, in a crane having one shaft and two pairs of wheels. Let such a crane have conical front wheels connected by a shaft, and cylindrical rear wheels with axial float but no shaft. Whichever direction the crane travels, the motion of the connected pair of wheels is not influenced by the free wheelers provided that the float is sufficiently great that it is never taken up during a complete cycle. Hence, the crane describes a sine curve of constant amplitude. The effect of the float, therefore, is to remove the damping when the crane travels forwards and the excitation when the crane travels backwards. This effect is good, since an exciting crane can cause considerable wear.

For the system to operate, the free wheels must have cylindrical treads, otherwise the wheels creep inwards to the extremity of their freedom and the crane thus loses the effect of the float. A disadvantage of the system is that two types of tread are involved, thus causing the head of the rail to bed down into two slopes. Each wheel then bears on only half the width of the rail. This is not serious on light cranes where the bearing pressure is less than the maximum allowable ; but on heavy cranes where the bearing pressure is critical, more wheels, bigger wheels or wider rails may be involved.

The effect of mal-alignment of the wheels

If the wheels are incorrectly aligned, the motion of the crane will be the same as that of the correctly built crane. Very slight extra wear of the treads will be experienced, however, because when the crane is running centrally and straight each pair of wheels is slightly off-set, so that they experience longitudinal creep.

† *" Some Experiments on the Lateral Oscillation of Railway Vehicles," by R. D. Davies, Journal of the Institution of Civil Engineers, Vol. II,* 1938-9, *Page* 232.

Spring loaded guide rollers

It has already been shown that a crane which is asymmetrical, back to front, describes a damped sine curve when travelling in one direction ; but that this advantage is off-set by an excitation when the crane travels in the opposite direction. The motion of a crane can only be regarded as completely satisfactory when its oscillations are damped whichever direction it travels. One way of producing this effect is by incorporating spring loaded rollers which press against the sides of the rails as shown in Figs. 19, 21 and 22. These rollers are arranged so that they provide a lateral restoring force whenever the crane becomes laterally displaced.

Consider a symmetrical crane having two shafts, two pairs of conical wheels and one pair of guide rollers as shown in Fig. 19. Let the lateral restoring

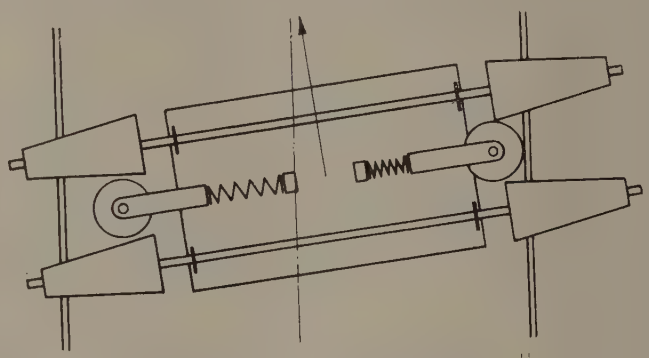

Fig. 19

force be F, and let it be proportional to the lateral displacement, y, of the mid-point of the crane, thus

$$F = -ky \quad . \quad . \quad . \quad . \quad (33)$$

where k is the stiffness of the springs. This force is reacted by lateral shear forces between rails and wheels, and from Equation (1), this produces an inward lateral creepage of

$$-\frac{ky}{4W\mu}.$$

Hence, by equating this to the geometrical formula for creepage,

$$\frac{dy}{dx} + \theta = -\frac{ky}{4W\mu} \quad . \quad . \quad . \quad (34)$$

is obtained. Eliminating θ from this equation and Equation (18)

$$\frac{d^2y}{dx^2} + \frac{k}{4\mu W}\frac{dy}{dx} + \frac{4}{mDS\left(1 + \frac{b^2}{S^2}\right)}y = 0, \quad . \quad (35)$$

the solution of which may be written

$$y = Ae^{-px} \sin\sqrt{(q^2 - p^2)}x \quad . \quad . \quad (36)$$

where

$$p = \frac{k}{8\mu W} \quad . \quad . \quad . \quad . \quad (37)$$

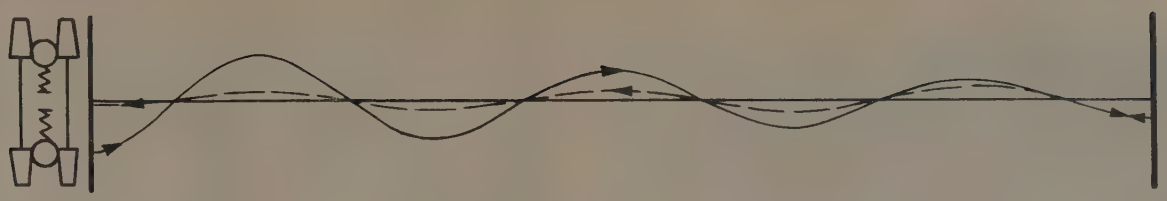

Fig. 20

and

$$q = \sqrt{\left[\frac{4}{mDS\left(1+\frac{b^2}{S^2}\right)}\right]}, \quad . \quad . \quad (38)$$

the origin of the axis of x being chosen suitably. This shows that the crane travels in a damped sine curve, the wave-length being given by

$$\lambda = \frac{2\pi}{\sqrt{(q^2 - p^2)}}, \quad . \quad . \quad . \quad (39)$$

and the damping factor being given by

$$\rho = e^{-\lambda p}. \quad . \quad . \quad . \quad . \quad (40)$$

If the crane reverses, it does not in this case retrace its tracks, but its oscillations continue to damp with the same damping factor. This is clear from Equations (37) and (38) since p and q are independent of the sign of b. The motion of the crane is illustrated in Fig. 20.

Better results can be obtained with two pairs of guide rollers arranged as shown in Fig. 21. In this

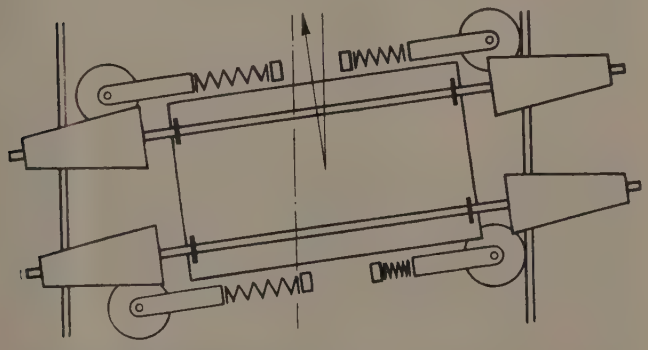

Fig. 21

case the rollers not only provide a restoring lateral force when the crane is displaced laterally, but they also provide a restoring moment when the crane is displaced angularly.

Now consider a crane with two pairs of wheels, only one of which is connected with a shaft, as shown in Fig. 22. Since the crane is now asymmetrical, there is no reason why the pair of guide rollers should be placed centrally. In fact, they may be better placed in some other position, and it will be assumed for the present that they are at a distance d behind the centre of the crane, as shown in the figure.

As before, let the force in the roller be proportional to the displacement of the roller, thus

$$F = -k(y + \theta d). \quad . \quad . \quad . \quad (41)$$

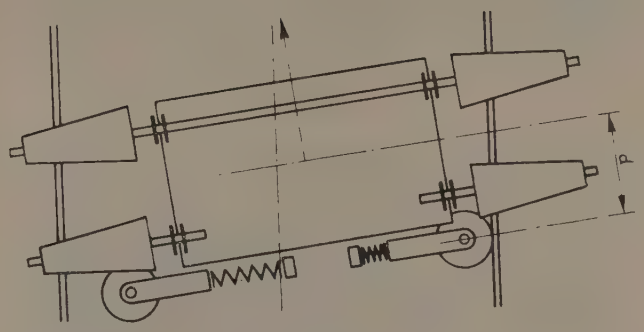

Fig. 22

This produces a lateral creepage

$$-\frac{k(y + \theta d)}{4\mu W},$$

and hence,

$$\frac{dy}{dx} + \theta = -\frac{k(y + \theta d)}{4\mu W}. \quad . \quad . \quad (42)$$

Taking moments about the mid-point of the crane, and remembering that the force F can be replaced by an equal force at the middle of the crane together with a couple Fd, the equation

$$-W\mu b^2\frac{d\theta}{dx} - \frac{S^2 W\mu}{2}\frac{d\theta}{dx} + \frac{2W\mu S}{mD}\left(y - \frac{b}{2}\theta\right) - Fd = 0 \quad (43)$$

is obtained. Eliminating F and θ from Equations (41), (42) and (43),

$$\left(1+\frac{2b^2}{S^2}\right)\frac{d^2y}{dx^2} + \left[\left(1+\frac{2b^2}{S^2}\right)\frac{k}{4\mu W} + \frac{2b}{mDS} - \frac{2kd}{S^2 W\mu}\right]\frac{dy}{dx}$$

$$+\left(\frac{4}{mDS} + \frac{kd}{mDSW\mu} + \frac{bk}{2mDSW\mu} + \frac{2kd}{S^2 W\mu}\right)y = 0. \quad (44)$$

The damping factor depends on the term

$$\left(1+\frac{2b^2}{S^2}\right)\frac{k}{4\mu W} + \frac{2b}{mDS} - \frac{2kd}{S^2 W\mu}.$$

The damping factor is, therefore, equal for forwards and backwards travel when the value of this term is unaltered by changing the signs of b and d together, that is when

$$\frac{2b}{mDS} = \frac{2kd^2}{S^2 W\mu}$$

or when

$$d = \sqrt{\frac{bSW\mu}{mDk}}. \quad . \quad . \quad . \quad (45)$$

This is the best value for d, since if d has any other value the damping factor will be increased for one direction of travel, and decreased for the other. Substituting for d from Equation (45) into Equation (44),

$$\frac{d^2y}{dx^2} + \frac{k}{4\mu W}\frac{dy}{dx}$$

$$+\frac{4}{mDS}\left[\frac{1+\sqrt{\frac{bk}{mDSW\mu}}\left(\frac{S}{4}+\frac{mD}{2}\right)+\frac{bk}{8W\mu}}{1+\frac{2b^2}{S^2}}\right]y=0, \quad (46)$$

the solution of which may be written

$$y = Ae^{-px}\sin\sqrt{(q^2-p^2)}x \quad . \quad . \quad (47)$$

where

$$p = \frac{k}{8\mu W} \quad . \quad . \quad . \quad . \quad (48)$$

and

$$q = \sqrt{\left[\frac{\frac{4}{mDS}\left\{1+\sqrt{\frac{bk}{mDSW\mu}}\left(\frac{S}{4}+\frac{mD}{2}\right)+\frac{bk}{8W\mu}\right\}}{1+\frac{2b^2}{S^2}}\right]}$$

$$. \quad . \quad . \quad . \quad (49)$$

the origin of the axis of x being chosen suitably. Hence, the crane again travels in a damped sine curve, the wave-length being given by

$$\lambda = \frac{2\pi}{\sqrt{(q^2-p^2)}}, \quad . \quad . \quad . \quad (50)$$

and the damping factor being given by

$$\rho = e^{-\lambda p} \quad . \quad . \quad . \quad . \quad (51)$$

equally for both directions.

Wheels with Treads of varying Slope

Parabolic treads

There is another method of producing the lateral restoring force, which does not involve the mechanical complexity of spring loaded guide rollers. This is to give the wheel treads varying slopes. Consider for example a pair of wheels having parabolic profiles as shown in Fig. 23.

Now if the crane has a lateral displacement y, the effective diameter of one wheel is increased by

$$\frac{2}{m}y + \frac{k}{4W}y^2$$

and the effective diameter of the other is decreased by

$$\frac{2}{m}y - \frac{k}{4W}y^2.$$

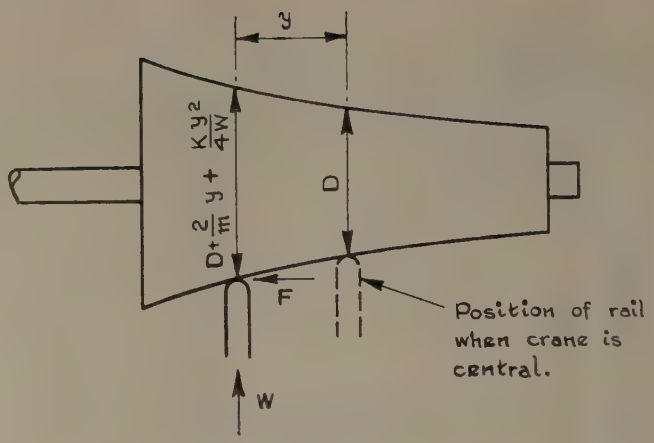

Fig. 23

Therefore the difference in diameter is

$$\frac{4}{m}y$$

which is linear in y and is the same as for plain conical wheels. The rail has a component of lateral force on the wheel which is proportional to the angle of slope of the tread at that point. Thus, on one of the wheels the force is

$$-\frac{d}{dy}\left(D+\frac{2}{m}y+\frac{k}{4W}y^2\right)W$$

and on the other the force is

$$\frac{d}{dy}\left(D-\frac{2}{m}y+\frac{k}{4W}y^2\right)W$$

Differentiating and adding these quantities gives the total lateral force on the pair of wheels, thus

$$F = -ky \quad . \quad . \quad . \quad . \quad (52)$$

which is linear in y and gives the same result as one pair of spring loaded rollers with springs of stiffness k, and placed in line with the wheels. It will be noticed that with plain conical wheels the two lateral forces from the two opposite wheels cancel each other, and therefore have no beneficial effect.

Half-conical and double-conical treads

Parabolic wheels have the disadvantage that they only give a point contact with the rail and therefore high bearing pressures result. This disadvantage can be overcome by having half-conical wheels of the type shown in Fig. 24(a). These tend to wear

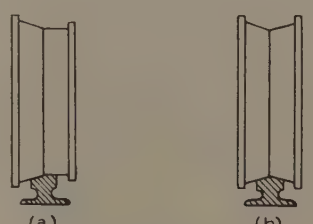

Fig. 24

the rail head into two distinct flats, and the bearing length at any one time is only half the width of the rail.

Free wheels, unconnected by shafts, may have double-conical treads of the kind shown in Fig. 24(b) and this has the advantage that twice the restoring force is present for the same coning angle. The double-conical tread should not be used, however, when the wheels are connected by a shaft, otherwise the steering effect of conical wheels is lost. Also, if the span of the gantry is a little greater than the span of the wheels, double-conical wheels connected with a shaft would have the effect of steering the crane away from the centre.

If both half-conical and double-conical wheels are used on the same crane the rail heads will tend to wear to three separate flats. If the wheel loading is light this is no disadvantage, but if it is heavy it may be best to avoid it. This can be done either by having half-conical wheels throughout, or by having plain conical wheels where the wheels are connected, and double-conical wheels where they are unconnected.

When half-conical or double-conical wheels are used on a crane, its motion can no longer be represented by any of the previous equations. This is because the correcting force from the wheels is no longer proportional to the displacement, but is a constant and merely changes sign as the wheel crosses the centre line of the rail. Thus the wave-length and damping factors are no longer independent of the amplitude.

A model crane was used to determine the damping factors and wave-lengths for cranes fitted with half- and double-conical wheels. The results of these tests are given in Table I.

Experiments done with the model have shown that there is no advantage in using half- or double-conical wheels on cranes without shafts. The correcting forces induced by the wheels are too mild to overcome those due to flange action and unequal tractive forces.

The Model Cranes

The model crane shown in Plates I to V was used to verify the theory given previously in this paper and to find the results given in Table I. The railtrack was 12 feet long and 1 foot gauge. The rails were made of 1 inch by 1 inch by $\frac{1}{8}$ inch steel angle section, and the tops of the rails were filed flat and chamfered so that the width of the bearing surfaces was $\frac{1}{32}$ inch. The rails were lined and levelled to within ± 0.015 inches everywhere.

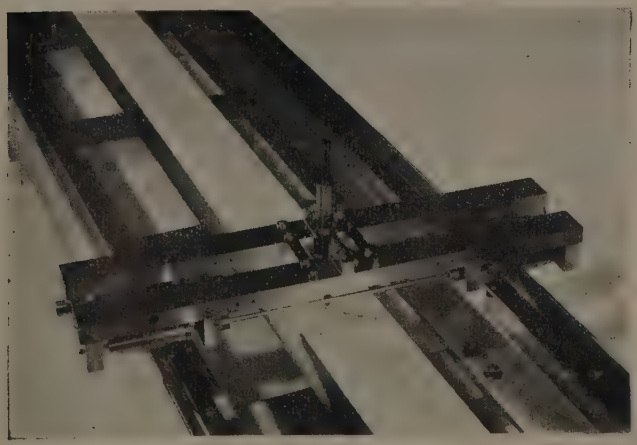

Plate 1.—General view of the railtrack and crane with tracing device

Plate 2.—Crane having 4 pairs of wheels

Plate 3.—Underneath view of crane having 4 pairs of wheels

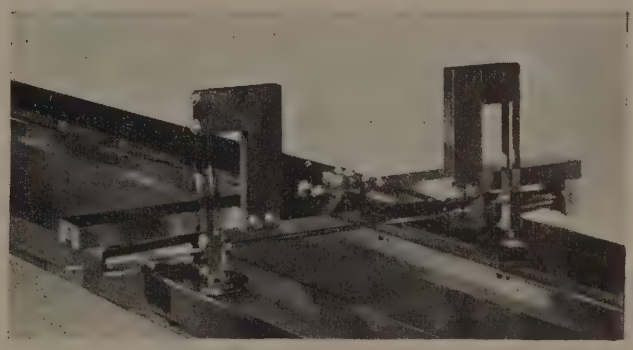

Plate 4.—The spring loaded side rollers (part of the crane is removed)

Plate 5.—Cylindrical, conical, half-conical and double-conical wheels

The crane parts were interchangeable so that various cranes with either 2 or 4 pairs of wheels could be constructed. The bearings for each pair of wheels were mounted on a solid steel bar 16 inches long; but the bars were joined together with a system of flat strips of spring steel. This allowed one bar to tilt relative to another and thus maintain equal bearing pressures on all wheels. The strips of spring steel were arranged in such a way that no other freedom was allowed between one bar and another, so that the motion of the crane was unaffected by them.

In all the experiments with cranes having 2 pairs of wheels, the wheel base, b, was $2\frac{1}{2}$ inches. The cranes with 4 pairs of wheels had the wheels spaced as shown in Fig. 25. All the wheels had an effective tread width of 2 inches and a diameter of $\frac{3}{4}$ inch at the mid-section. The plain conical and double-conical wheels had a coning cotangent of 16 :1. The treads of all the wheels were ground to a tolerance of ± 0.0005 inch.

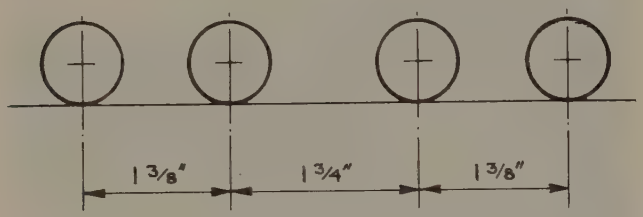

Fig. 25

The motion of cranes fitted with cylindrical tread wheels was determined from measurements made directly from the crane when on the railtrack.

In order to measure wave-lengths and damping factors for cranes fitted with conical, half-conical and double-conical wheels, a holder which supported a ball point pen was attached to the crane. This is shown in Plate I. The pen was held so that its axis was vertical and the ball of the pen was vertically underneath the geometric centre of the crane. The pen was allowed movement along its axis only, and a load of two ounces was placed on it. A strip of paper was placed underneath the crane so that the crane path was traced by the ball pen.

The crane was first set up at one end of the track, squarely across it, and with a measured sideways displacement. The crane was pulled along the track by a piece of thread, attached to the mid-point of the crane. Care was taken to keep the thread horizontal and at right angles to the body of the crane.

Thus the crane traced its path on the paper and a curve such as a, a_1, a_2, . . . in Fig. 26 was produced. The crane was then returned to its starting point, set squarely across the track again and given an equal but opposite displacement. On pulling the crane down the track again a curve such as b, b_1, b_2, . . . was described. The experiment could, of course, be repeated with any other initial displacements, thus giving a wide range of amplitudes.

To find the damping factor from these traces, the distances $2y_0$, $2y_1$, $2y_2$, . . . were measured, and a graph was plotted showing $2y_n$ against $2y_{n-2}$. In the case of cranes having conical wheels but no half- or double-conical wheels the graph was a straight line and the slope represented the damping factor. For cranes using half- or double-conical wheels, however, the graphs were no longer straight. In Table I the damping factors quoted correspond to an amplitude of ± 0.05 inch of the model, and these were found by measuring the slope of the tangent at this point on the graph. This amplitude corresponds to an amplitude on a 100-foot span crane of about ± 5 inches.

A graph of wave-length against damping factor was also drawn so that the wave-length corresponding to an amplitude of ± 0.05 inch could be measured. The results are shown in Table I.

Conclusions and Recommendations

Wheel and axle systems

For the purpose of studying the relative merits of different systems, cranes may be classified in five main groups :

(a) Systems without shafts,
(b) Cylindrical tread systems,
(c) Conical tread systems which are symmetrical (that is the same front and rear),
(d) Conical tread systems which are asymmetrical,
(e) Half- and double-conical tread systems.

The first two of these systems are similar except that cranes without shafts are very much more sensitive (in fact too sensitive) and are adversely affected by motors having different torques. The general recommendation is that cranes should have shafts. But where there is some special reason that a shaft should not be used, good results can be obtained by using guide rollers. This type of crane should have cylindrical wheels. Cranes without either shafts or guide rollers are unreliable.

A cylindrical tread system is sound if the crane is constructed accurately and remains so, but some errors in the crane, which are certain to occur in practice, cause the crane to run skew-wise. This causes flange wear if the distance the crane is expected to travel is greater than the free running distance. Because of these defects, cylindrical tread systems are not recommended unless either the distance over which the crane operates is small (that is, within the free running distance), or guide rollers are fitted.

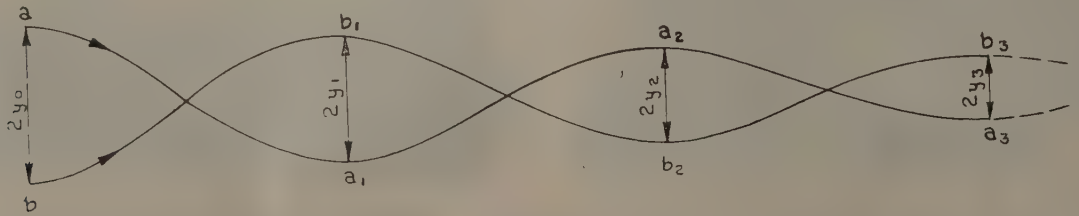

Fig. 26

A conical tread system is good provided the crane is symmetrical front to rear. In this case the crane is expected to describe a sine curve of constant amplitude and, therefore, no serious binding can take place except when the rails are not straight. Such a crane is satisfactory, though two shafts are involved which increases the cost.

On the other hand, ordinary conical wheels should not be used on asymmetrical cranes, where for example there is only one shaft connecting one pair of wheels. In this case the crane excites when travelling in one direction, and if the crane is expected to travel long distances flange wear will result. This fault can be overcome to some extent by allowing axial float in the free wheels, and can be completely overcome by means of guide rollers.

For both symmetrical and asymmetrical cranes, half-conical and double-conical wheels will improve the motion. They should be arranged so that the damping factor is less than unity for both directions of travel. There is only one disadvantage of the wheels and that is that the effective bearing width is only half the width of the rail. While this is an important consideration in very heavy duty cranes it is usually of little consequence and can in any case be taken into account in design. Many wheels of existing traditional cranes bear on only half the rail width where the crane has conical driving wheels and cylindrical trailers.

Axial float in the wheels

No axial float should be permitted in any cranes with cylindrical tread systems, or in any cranes without cross shafts. Also, no axial float should be permitted in a pair of coned wheels unless the wheels are kept a fixed distance apart by means of a direct cross shaft. Subject to these rules there is neither harm nor advantage in using axial float in conical tread systems which are symmetrical.

The only case where axial float is an advantage is in asymmetrical conical tread systems. For example, in a crane with a pair of conical wheels connected with a shaft in front and a pair of cylindrical free wheels behind, it would be an advantage to allow axial float in the free wheels.

No axial float should be used in conjunction with half- and double-conical tread systems.

No wheel should have any freedom to steer relative to the crane. In cranes having 4 or 8 pairs of wheels it is common to mount the wheels in pairs in bogies. In such cases the bogies should have no freedom to steer.

Guide rollers

Guide rollers fall into three distinct categories : spring loaded, rigid, and composite. The spring loaded rollers provide a restoring force whenever the crane is not exactly central. The rigid rollers do not do this but take the place of the wheel flanges in providing a limit to the extent to which the crane can displace laterally. A composite roller does both of these things, and as the lateral displacement of the crane increases, the spring supporting the roller continues to compress, ultimately coming against a rigid stop. In the case of rigid and composite rollers, the wheel flanges are not required.

Spring loaded and composite rollers improve the behaviour of cranes in every sense, but rigid rollers do not alter the tendency of a crane to run skew-wise. They only replace the flange binding with a roller action which, of course, is a more satisfactory mechanical arrangement.

All cranes without shafts are unreliable unless guide rollers are fitted. All cranes with shafts but having cylindrical tread systems are unreliable without guide rollers unless their normal service only requires them to operate over a short length of track. The guide rollers may be of any of the three kinds.

Symmetrical conical tread systems give satisfactory service, and there is, therefore, not much advantage in fitting guide rollers. In asymmetrical conical systems where the crane has to operate over a great length of track, spring loaded or composite guide rollers should be used to bring the damping factor to a figure not greater than unity for each direction of travel.

Although a single pair of spring loaded rollers may be used on conical tread systems, it is always necessary to have at least two pairs on cylindrical tread systems, or systems without shafts.

Guide rollers need not be fitted to cranes having half- and double-conical wheel systems.

The coning angle

The coning angle of conical wheels is usually 1:16, and there is no reason to suggest any change. The same coning angle should be used for half-conical and double-conical wheels.

Tread width and flange positions

One reason for having the tread width greater than the rail width is to accommodate local deviations of the rails and variations in the span of the gantry. Another reason is to increase the free running distance in certain types of cranes. The Author considers that the tread widths should be somewhat greater than is common practice today. Tread widths 5 inches greater than rail widths have already been used at Abbey Works with success. As an empirical working rule, the tread width could be about 5 inches greater than rail width for cranes of 100 feet span, with slightly smaller treads for smaller cranes. This applies to wheels with all types of tread.

It is customary, at present, to have two flanges to each wheel. There is no reason to change this practice except in cranes without shafts, in which case it is

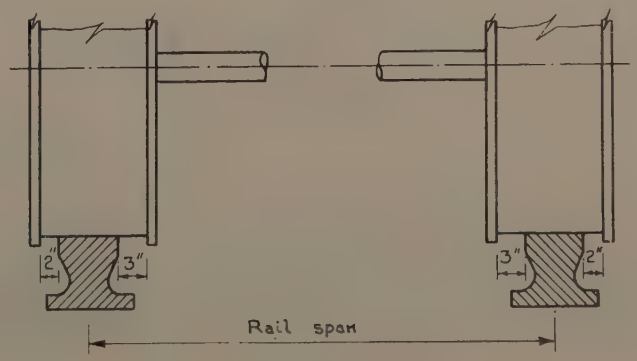

Fig. 27

preferable to have outside flanges only. If omitting the inside flanges is thought to be unsafe, then each inside flange should be moved towards the centre of the crane by about an inch so that the outside flanges are more generally used. This arrangement is shown in Fig. 27.

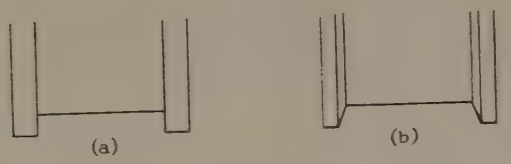

Fig. 28

Flange design

It has been customary to design square type flanges as shown in Fig. 28(a), but the Author considers that sloping ones, as shown in Fig. 28(b) are better. The sloping flanges are less likely to cut the side of the rail, and less likely to ride on to the rail. This recommendation is, incidentally, in keeping with railway practice.

The wheel base

Sometimes it is thought that the wheel base of a crane, that is the distance between the front and rear wheels, should be as great as possible to achieve a satisfactory performance. This is not always so, and the choice of wheel base depends upon the layout of the crane and the types of tread to be used. For the present, just three broad categories will be dealt with : cylindrical tread systems, symmetrical systems with conical treads, and asymmetrical systems with conical treads.

In the case of cylindrical tread systems the longer the wheel base the better. This can be seen from Equation (16), where, if δ is assumed constant, θ becomes smaller as b becomes greater.

In the case of a symmetrical crane having conical treads, the wheel base has little or no effect on the extent of flange wear.

In the case of an asymmetrical crane having conical treads, there is an advantage in having the wheel base as short as possible. As b becomes smaller, Equation (27) shows that p becomes smaller, and thus, from Equation (30), the damping factors for the forwards and backwards direction of motion become more nearly equal.

Acknowledgments

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Appendix I

Summary of Notation

a	width of rails
b	wheel base of crane having two pairs of wheels
D	mean wheel diameter
d	distance of guide rollers behind centre of crane
F	lateral force applied to crane
f_1	axial float of the front pair of wheels
f_2	axial float of the rear pair of wheels
k	stiffness of guide roller spring
m	cotangent of coning angle of wheels
N	number of pairs of wheels on crane
n	number of pairs of wheels coupled by shafts
P_1 and P_2	the tractive forces at the two ends of a crane without shafts
S	span of gantry
t	tread width of wheels
W	wheel load
x	distance of travel of crane along the track
y	lateral displacement of crane
α	lateral creepage
β	longitudinal creepage
δ	axial displacement of wheels in incorrectly built crane
θ	angle of skew of crane
λ	wave-length
μ	coefficient of creepage
ρ	damping factor

Appendix II

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An Investigation of the Stresses and Deflections in Castellated Beams

By J. E. Gibson, M.Sc.(Maths.), Ph.D., A.M.I.C.E.* and W. M. Jenkins, B.Sc., Grad.I.C.E.†

Summary

THE behaviour of castellated I beams which are primarily I beams with regularly spaced hexagonal holes in the webs is investigated for the case of bending in a simply supported centrally loaded beam. An approximate analysis is presented which presumes that the beam will behave as a vierendeel girder, this is followed by a photoelastic investigation in which a model castellated I beam is used. The second part of the experimental investigation is concerned with the stress distribution and deflections of actual steel castellated beams as supplied by the manufacturers. The derived theory is applied to both the latter and the previous photoelastic investigation. Finally the elementary beam theory as used by the manufacturers in compiling safe load tables is examined in relationship to the presented theory and the experimental results.

Introduction

The Authors in a previous paper[1] have investigated the stress distribution in a beam with a circular hole utilising stress functions. The utilisation of stress functions for single internal contours is relatively easy but their application to a multi connected region, such as is presented by castellated sections, is extremely complicated; especially when the internal contours are hexagonal. Because of the inherent complications of such a stress function analysis, the Authors decided to use a more practical approach to the theoretical problem.

Fortunately the work of L. Chitty and Professor A. J. S. Pippard[2], [3 and 4] in relation to the analysis of vierendeel girder types of structure, provided an approximate solution and their theories were modified to satisfy the particular requirements of the present problem.

This method of analysis, in which the stress theory for an open panelled structure has been applied to the case of a multi connected web structure, cannot of necessity predict local stress concentrations which may occur in the web of the section. However it will be seen that such stress concentrations, which are purely local, are unlikely to be critical in the determination of the safe loading capacity of the beam.

This approximate theory is then examined in relationship to experimental data obtained from photoelastic investigations and actual tests on castellated beams.

Both the theoretical and experimental work in this present paper have been limited to the elastic range but it is hoped that, in the near future, a similar investigation in the plastic domain will be presented.

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Theoretical Analysis

The method of analysis adopted in this paper is a modified form of that used by Chitty and Pippard[4] for open panel structures. The method is approximate and consists essentially in replacing the discontinuous web by a continuous medium which is designed to transmit actions to the flanges similar to those of the original web members.

Initially, let it be supposed that the structure to be examined consists of uniform members for the top and bottom chords and uniform vertical web members. It will be further assumed that the shortening of the vertical members due to axial thrust may be ignored.

Consider such an open panelled structure of span L carrying a uniformly distributed load of w along the top chord and let the lengths of the vertical members be l, let the verticals be uniformly spaced at a distance h apart.

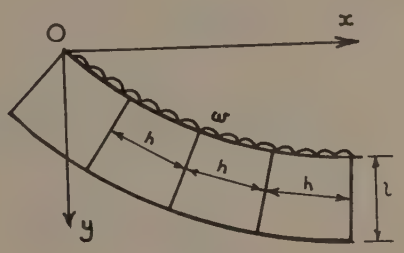


Fig. 1(a)

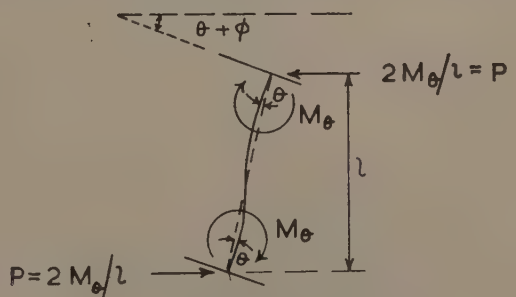


Fig. 1(b)

Consider Fig. 1, let the origin of the axes x, y be as shown i.e. at the support end of the top chord, the positive directions being as shown. Let the compressive and tensile forces in the top and bottom chords be P and the terminal moments acting on the vertical member be M_θ, for equilibrium obviously

$$Pl = 2M_\theta \therefore P = 2M_\theta/l \quad . \quad . \quad (1)$$

Now the axial force P will cause an angular deflection φ of the top chord and due to the end moment $M\theta$ the vertical member will rotate through an angle θ and if it be assumed that the joint between the chord and the vertical member is rigid this rotation of the vertical member will be communicated to the top chord. Thus the total angular rotation of the top chord will be $\varphi + \theta$. Thus immediately for the top chord we have

$$\frac{dy}{dx} = \varphi + \theta \quad . \quad . \quad . \quad (2)$$

which by convention will be assumed positive.

It will be assumed that the bottom chord suffers the same angular rotation. Now due to the axial thrust P the top chord at any section x will be shortened by an amount Δ and the bottom chord increased by an equal amount. If φ is the angular rotation caused by this deflection then obviously

$$\varphi = 2\Delta/l \quad . \quad . \quad . \quad . \quad (3)$$

If the cross sectional area of the chords is denoted by A then

$$\Delta = \int_{x}^{L/2} \frac{P}{AE}\, dx \quad . \quad . \quad . \quad (4)$$

and from (3) we have immediately

$$\varphi = \frac{2}{l}\int_{x}^{L/2} \frac{P}{AE}\, dx \quad . \quad . \quad . \quad (5)$$

where

$$P = \sum_{0}^{x} 2\, M_\theta/l \quad . \quad . \quad . \quad . \quad (6)$$

Again by considering the rotation of the vertical member due to the end moments M_θ, it is easily proved that its end rotation θ is given by

$$\theta = M_\theta l/6EI_c. \quad . \quad . \quad . \quad (7)$$

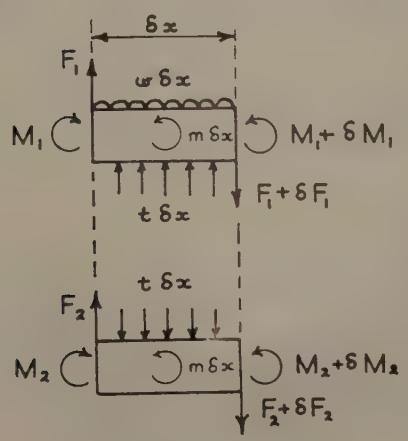


Fig. 2

Now let it be assumed that the vertical web members are replaced by a continuous web member that communicates a bending moment m per unit length and a thrust t per unit length to the top and bottom chords as shown in Fig. 2. It will be further assumed that these moments and thrusts produce the same stress distributions and deflections as did the original web verticals. The previous equations may be thus modified in the following manner. Equation (6) is replaced by

$$P = \int_{0}^{x} \frac{2m}{l}\, dx \quad . \quad . \quad . \quad (8)$$

whilst equation (5) now takes the form

$$\varphi = \frac{2}{l}\int_{x}^{L/2} \frac{1}{AE}\int_{0}^{x} \frac{2m}{l}\, dx\, dx. \quad . \quad . \quad (9)$$

Now if I^1 is the moment of inertia per unit width of the web, by comparison with (7) we have immediately

$$\theta = ml/6EI^1 \quad . \quad . \quad . \quad (10)$$

Now substituting equations (9) and (10) in (2) we have

$$\frac{dy}{dx} = ml/6EI^1 + \frac{2}{l}\int_{x}^{L/2} \frac{1}{AE}\int_{0}^{x} \frac{2m}{l} dx\, .\, dx. \quad . \quad (11)$$

Now consider Fig. 2 which represents elements of length δx of the top and bottom chords. Let the shear forces and moments acting on the elements be as shown whence considering the equilibrium of the elements we have immediately

$$\left.\begin{array}{lll} \text{(a)}\ \delta M_1 + m\delta x - F_1\delta x = 0 & \therefore \dfrac{dM_1}{dx} = -m + F_1 \\ \text{(b)}\ \delta F_1 + w\delta x - t\delta x = 0 & \\ \text{(c)}\ \delta M_2 + m\delta x - F_2\delta x = 0 & \therefore \dfrac{dM_2}{dx} = -m + F_2 \\ \text{(d)}\ \delta F_2 + t\delta x = 0 & \end{array}\right\} \quad (12)$$

Whence if M is the total moment acting at the section then

$$M = M_1 + M_2$$

and

$$\frac{dM}{dx} = \frac{dM_1}{dx} + \frac{dM_2}{dx} = -2m + F \quad . \quad (13)$$

from 12(a) and 12(c)

where $F = F_1 + F_2$ is the total vertical shear at the section.

Now using the normal Euler Bernoulli bending equation we have immediately that the total bending moment M is

$$M = -2\left(EI\frac{d^2y}{dx^2}\right) \quad . \quad . \quad (14)$$

and substituting this value of M in equation 13 then

$$\frac{d}{dx}\left(-2EI\frac{d^2y}{dx^2}\right) = -2m + F \quad . \quad (15)$$

Now differentiating equation (11) with respect to x

$$\left.\begin{aligned} &(a)\ \frac{d^2y}{dx^2} = \frac{l}{6EI^1}\frac{dm}{dx} - \frac{2}{lAE}\int_0^x \frac{2m}{l}\,dx \\ &(b)\ \frac{d^3y}{dx^3} = \frac{l}{6EI^1}\frac{d^2m}{dx^2} - \frac{2}{lAE}\cdot\frac{2m}{l} \end{aligned}\right\} \quad . \quad . \quad (16)$$

whence substituting equation 16(b) in (15)

$$-2EI\left\{\frac{l}{6EI^1}\frac{d^2m}{dx^2} - \frac{2}{lAE}\cdot\frac{2m}{l}\right\} = -2m + F \quad (17)$$

and writing

$$EIl/6EI^1 = 1/\alpha^2 \quad . \quad . \quad . \quad (18)$$

and

$$k^2 = I/A \quad . \quad . \quad . \quad . \quad (19)$$

equation (17) eventually reduces to

$$\frac{d^2m}{dx^2} - \mu^2 m + \frac{\alpha^2}{2}F = 0 \quad . \quad . \quad (20)$$

where

$$\mu^2 = \alpha^2\left\{1 + \frac{4k^2}{l^2}\right\} \quad . \quad . \quad . \quad (21)$$

Now the solution of equation (20) is easily proved to be

$$m = A\ cosh\ \mu x + B\ sinh\ \mu x + \frac{\alpha^2}{2\mu^2}F \quad . \quad (22)$$

where A and B are arbitrary constants and F is the total shear at the section.

Again from equations (12) it may be proved that

$$\frac{dF}{dx} = -w \quad . \quad . \quad . \quad (23)$$

and that

$$\frac{1}{2}\frac{dF}{dx} = -t \quad \text{or} \quad t = \frac{w}{2} \quad . \quad . \quad (24)$$

On substituting the expression for m as given by equation (22) in equation (16b) and integrating, an expression for the vertical deflection of the chords may be obtained. However as the experimental work was limited to the investigation of stresses and deflections in simply supported girders, centrally loaded, only this case will now be derived.

Simply Supported Girder carrying Central Point Load

In the case of a simply supported girder of length L and carrying a central point load W the vertical shear is constant i.e.

$$F = +W/2 \quad . \quad . \quad . \quad (25)$$

and $t = 0$ from equation (24) as F is constant and thus equation (22) reduces to

$$m = A\ cosh\ \mu x + B\ sinh\ \mu x + \frac{\alpha^2}{2\mu^2}\cdot\frac{W}{2} \quad . \quad (26)$$

and the following conditions must exist at

$$\begin{cases} x = L/2, & \dfrac{dy}{dx} = 0 \\ x = 0, & \dfrac{d^2y}{dx^2} = 0 \end{cases}$$

these conditions for y must be immediately interpreted as conditions for m by using equation (16).

Using the first conditions in equation (11) then at $x = L/2$, $m = 0$ and the second condition in (16)a then at $x = 0$, $\dfrac{dm}{dx} = 0$.

These two conditions on substituting in equation (22) give

$$\left.\begin{aligned} A &= -\frac{\alpha^2 W}{4\mu^2\ cosh\ \mu L/2} \\ B &= 0 \end{aligned}\right\} \quad . \quad . \quad (27)$$

Substituting these values of the arbitrary constants in equation (26) we have finally

$$m = -\frac{\alpha^2 W}{4\mu^2}\left\{\frac{cosh\ \mu x}{cosh\ \mu L/2} - 1\right\} \quad . \quad (28)$$

Now substituting this value for m in equation (16b) and using the relevant end conditions, it may be easily proved that the deflection y is given by

$$\left.\begin{aligned} &(a)\ y = \frac{W}{4EI}\left\{\lambda\left(\frac{L^2x}{8} - \frac{x^3}{6}\right)\right. \\ &\qquad \left. + \frac{x}{\mu^2}(1-\lambda) - \frac{sinh\ \mu x}{\mu^3\ cosh\ \mu L/2}(1-\lambda)\right\} \\ &(b)\ \alpha^2 = 6EI^1/EIl \\ &(c)\ I^1 = nIc/L = Ic/h \text{ where } h = 1.08\,d \\ &(d)\ k^2 = I/A \\ &(e)\ \mu^2 = \alpha^2(1 + 4k^2/l^2) \\ &(f)\ \lambda = 4k^2\,\alpha^2/l^2\mu^2 \end{aligned}\right\} \quad (29)$$

Now the chord force P is given by

$$P = \int_0^x \frac{2m}{l}dx = \frac{2}{l}\cdot -\frac{\alpha^2 W}{4\mu^2}\left\{\frac{sinh\ \mu x}{\mu\ cosh\ \mu L/2} - x\right\} \quad (30)$$

and in the interval $0 < x < L/2$ $\dfrac{sinh\ \mu x}{cosh\ \mu L/2} \to 0$

Finally since $\dfrac{\alpha^2}{\mu^2} = 1/(1 + 4k^2/l^2)$ and $4k^2/l^2$ is very small i.e. $\dfrac{\alpha^2}{\mu^2} \to 1$, then equation (30) reduces to the

following approximate expression for P

$$P \simeq \frac{Wx}{2l} \quad . \quad . \quad . \quad . \quad (31)$$

The actual bending moment $M\theta$ in the real structure will be given by

$$M_\theta = \int_{-h/2}^{+h/2} m \,.\, dx = \left[\frac{-\alpha^2 W}{4\mu^2}\left(\frac{2\,sinh\,\mu h/2}{\mu\,cosh\,\mu L/2} - h\right)\right]$$

and again in the interval $0 < x < L/2$ this reduces to the following approximate equation

$$M_\theta \simeq Wh/4 \quad . \quad . \quad . \quad (32)$$

where h is the distance between the centre lines of adjacent castellations i.e. between the centre lines of the adjacent verticals.

Application of the theory to Castellated Beams.

The preceding theory will now be applied to the case of castellated sections, the shapes of which are shown in Fig. 3. These sections are formed by cutting a standard rolled steel joist of depth d to the half hexagonal form shown in the figure separating and then welding along the centre line as indicated. The resulting depth of the so called castellated section is thus increased to $1.5d$, the resulting geometrical shape and other dimensions being as shown in Fig. 3.

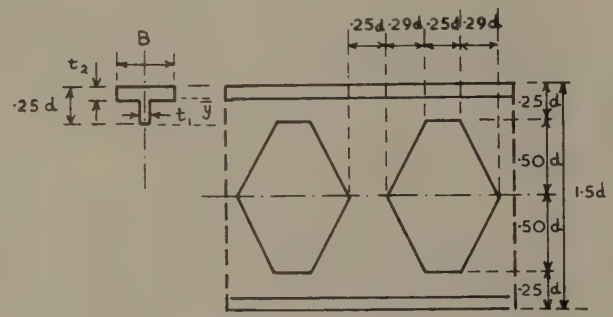


Fig. 3

In applying the preceding theory to such castellated sections it will be assumed that the top and bottom flanges of the beam are T sections as shown in Fig. 3 and that the verticals consist of the dashed line $ABCDEF$, as shown in Fig. 4. The overall length of the verticals is $l = 2b$, b being measured from the centre line of the section as a whole to the neutral axis of a flange section.

By considering the shape of the top and bottom flanges it is easy to show that if the cross section is assumed to be a regular T, as shown in Fig. 3 then the cross sectional area will be given by

$$A = Bt_2 + t_1 y \quad . \quad . \quad . \quad (33)$$

where

$$y = 0.25\,d - t_2$$

The distance of the neutral axis $\bar{y}$ from the bottom edge of the section is

$$\bar{y} = \left\{Bt_2\,(y + 0.5t_2) + t_1 y^2/2\right\}/A \quad . \quad (34)$$

and finally the moment of inertia I of the section about the neutral axis is given by

$$I = Bt_2^3/12 + Bt_2\left\{y + 0.5t_2 - \bar{y}\right\}^2 + t_1 y^3/12 + t_1 y\left\{\bar{y} - y/2\right\}^2 \quad . \quad . \quad . \quad . \quad (35)$$

It will be found that in the majority of manufactured rolled steel sections, that are castellated, that $\bar{y} \simeq y$.

It is now necessary to examine the bending of the vertical member $ABCDEF$ shown in Fig. 4. It is relatively easy to show that the end rotation θ of this member due to the terminal couples M_θ is given by the equation

$$\theta = \frac{M_\theta \,.\, 2b}{6EI_c} \quad . \quad . \quad . \quad (36)$$

where

$$2b = 1.5d - 2t_2$$

and where

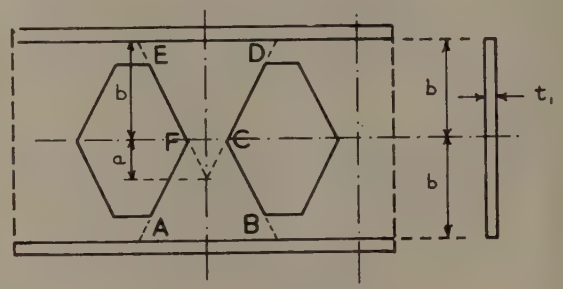


Fig. 4

$$\left.\begin{aligned} &(a)\ \frac{I}{Ic} = \frac{3}{k_1 b^2}\left\{\frac{-3}{2(a+b)} + \frac{a}{2(a+b)^2} + \frac{1}{b}log\frac{a+b}{a}\right\} \\ &(b)\ k_1 = 0.129t_1 \\ &(c)\ a = 0.216d \end{aligned}\right\} \quad (37)$$

Equations (33-37) thus provide sufficient information to allow the fundamental constants k^2, α, μ and λ as given by equation (29) to be calculated. Having determined these constants it is then necessary to examine the various stress systems caused by the chord force P and the terminal moments M_θ.

The chord force P will produce a direct chord stress fc which will be given by

$$f_c = \pm\, P/A \quad . \quad . \quad . \quad (38)$$

where P is given by equation (31) and A by equation (33).

Now the terminal moments M_θ acting on the verticals must be balanced by equal counter moments M_θ in the chords and if it is assumed that these counter moments are each composed of two counter moments $M_\theta/2$ as shown in Fig. 5 then each of these sections of the chords will bend under the influence of these couples, giving obviously a point of inflexion at x, the centre of the bridge of the castellation.

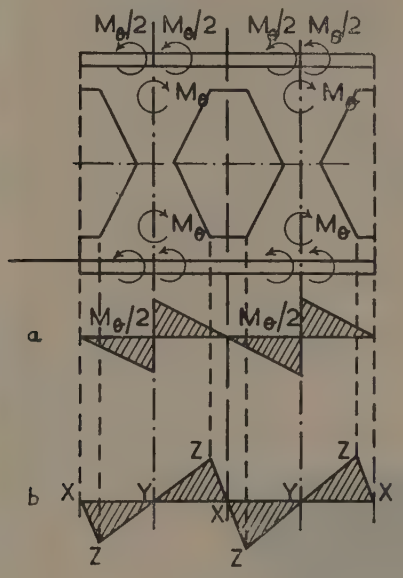


Fig. 5

It is equally obvious that points of inflexion will occur at YY, the theoretical bending moment diagram being as shown in Fig. 5a. An analysis of the stress distribution due to this bending indicated that maximum stresses occured at the points ZZ in the figure and that the resulting curve of the stress distribution was as shown in Fig. 5b.

As the bending moment distribution is given by

$$Mx = \frac{M_\theta}{2} \cdot \frac{x}{0.54d}$$

then the bending stress equation is obviously

$$fx = \frac{M_\theta \,.\, x \,.\, y}{1.08d \,.\, I} \quad . \quad . \quad . \quad (39)$$

where $y = 0.25d - \bar{y}$ and x is limited to the range $0 < x \leq .54d$ which gives maximum values at $x = .125d$ i.e. at the points ZZ.

The resulting flange stress is then the algebraic sum of the direct stress as given by equation (38) and the bending stress as given by equation (39) i.e.

$$f = fc + fx \quad . \quad . \quad . \quad (40)$$

The stress distribution in the vertical members must now be examined. The bending moment diagram due to the terminal moments M_θ will be as shown in Fig. 6 and it may be shown that the stresses at the extreme edges of the vertical members is given by the equation

$$fx = \frac{3M_\theta \,.\, x}{2bt\,c^2 \;\; (a + x)^2} \quad . \quad . \quad (41)$$

where $a = 0.216d$ and $c = 0.5774$.

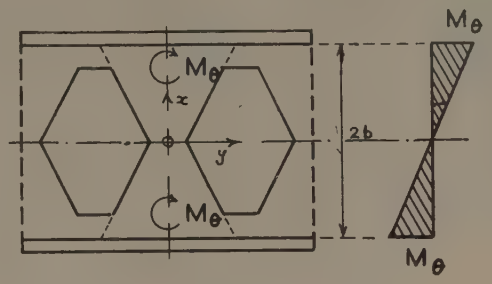


Fig. 6

This completes the stress analysis for the beam, the deflections being given by equation (29). In order to attempt to verify this theory, two types of experiment were conducted the first set consisted of photoelastic investigations on model castellated sections and the second were stress and deflection investigations of actual steel castellated sections as supplied by the manufacturers.

Photoelastic Investigation.

Before conducting tests on actual steel castellated sections it was decided to investigate photoelastically the stress distribution in a model beam. By this means valuable information as to the nature of the stress distribution was obtained, the regions of maximum stress distribution being clearly indicated. This information proved invaluable in locating the positions of the gauges for the examination of critical stresses in the steel beam tests. Examination of the stress fringe patterns soon showed that in all cases the edge stresses were critical both in the flanges and around the hexagonal holes and that the investigation of the stresses in the interior of the web i.e. the centre lines of the verticals, was not nearly so important. Further the photoelastic analysis allowed a direct comparison between the theoretical and experimental results to be made.

The models were machined from C.R.39 so that the resulting I section had flanges $\frac{3}{8}$ inches wide by $\frac{1}{8}$ inches thick and a web $\frac{1}{8}$ inches thick, the overall depth of the section being one inch. The dimensions and spacing of the holes were geometrically similar to that of the actual castellated section as shown in Fig. 7. To allow the accurate determination of the fringe order in the web, its thickness was relatively increased allowing a greater number of stress fringes to be formed than if the true scale for the section had been used. Owing to the brittle nature of the material it was decided to limit the span of the model to eight clear castellations as this allowed sufficient stress fringes to be developed without failure occurring due to too high bending stresses. The model was subjected to a central load of 53.5 lbs. and the resulting stress fringes were observed under monochromatic circularly polarised light, the stress fringe photograph is shown in Fig. 8. Examination of these stress fringes shows that uniform stress distribution occurs along the major portion of the edges of the holes i.e. the edges of the verticals, save at the extreme corners where marked stress concentrations occur due to the acuteness of the contour there. An exact plot of the stress distribution is shown by the full line in Fig. 9.

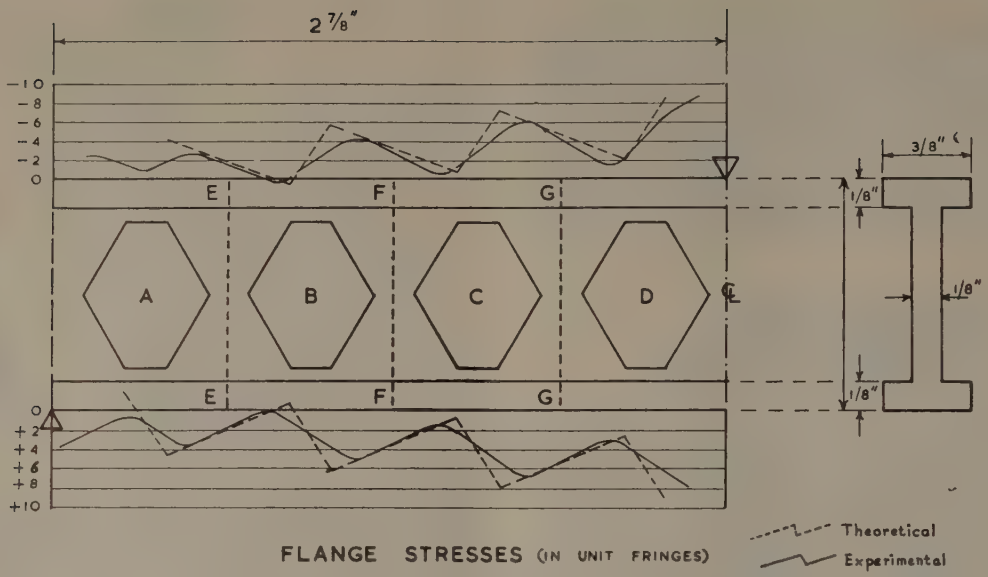


Fig. 7

Fig. 8

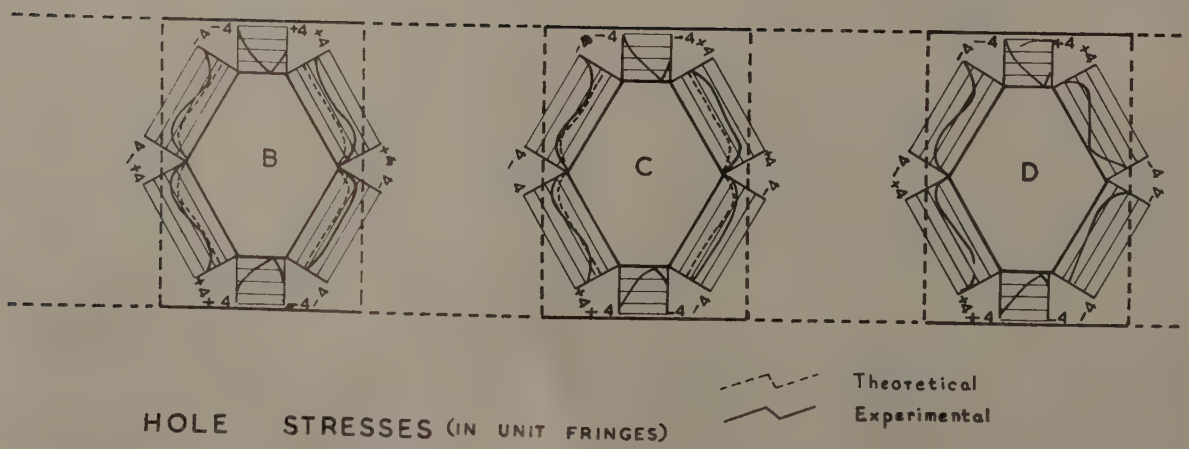


Fig. 9

The flange stresses plotted in unit fringes are shown as the full lines in Fig. 7.

Substituting the relevant dimensions of the model in formulae (35) it was found that the moment of inertia I of the top and bottom flanges was 0.0000946 ins.^{4}. From the span length which was 5.75 ins., the rest of the constants were determined using equation (29). As these constants are used only in equation (29a) for calculating the deflection of the beam and as these deflections were not determined experimentally, they will not be further investigated herein.

The chord stress was determined from equation i.e. (31) and (38)

$$fc = \frac{W}{2l \,.\, A} \,.\, x = 600\, x \text{ lbs./sq. in.}$$

and this translated into stress fringes gives

$$n_c = \frac{fc \,.\, t}{2F}$$

unit fringes where t is the thickness and F is the material fringe value 48.5 lbs./sq. in./in. hence $n_c = 2.31x$ unit fringes.

Using equation (39) the maximum values of the bending stresses were found to be $n_b = \pm 3.22$ unit fringes. These equations allowed the resulting flange stress distribution to be obtained, the maximum and minimum values being obtained from their algebraic sum namely $n = n_c + n_b = 2.31x \pm 3.22$ unit fringes.

The complete plot of this flange stress distribution is shown in Fig. 7 as the dotted line where it will be seen that agreement between theory and experiment is quite good.

The stress distribution in the vertical members was now examined by direct substitution in equation (41), the equation translated in terms of unit fringes was found to be

$$n = 1.03 \,.\, \frac{x}{(a + x)^2}$$

unit fringes.

The plot of these stresses is shown in Fig. 9 as the dashed line. Again it will be observed that agreement between theory and experiment was reasonable, save at the extreme corners of the castellation where localised stress concentrations occurred. Further photoelastic tests on models revealed that the same type of stress distribution as those observed above existed and it was concluded that the theoretical results gave a close approximation to the stress distribution in such castellated sections. The photoelastic investigation having provided clear experimental evidence as to the nature of the stress distribution in castellated I sections, tests on the actual steel beams were then carried out. Vertical shear stresses were determined for the sections EE, FF and GG, their shape and magnitude indicated that the vertical shear distribution was constant. These are shown in Fig. 10. Such stresses were not examined in the steel tests.

Tests on 9″ by 3″ Castella I Sections

The Authors have conducted numerous tests on castella I sections in the Department of Civil Engineering, University of Glasgow, these tests provided much experimental data on the behaviour of such sections under various loading conditions. The tests described herein however are a complete set of tests on a 9″ by 3″ I section in which the span was varied from eight to twelve clear castellations. These latter tests were conducted in the Civil Engineering Department, of the University of Manchester.

In order to test the validity of the previously outlined theory it was decided to measure the flange stresses, the stresses around the edges of the castellations and finally the vertical deflections under known loading conditions.

Test on 9″ by 3″ Castella Section simply supported and loaded centrally

The first test of the series was on a 9″ by 3″ I section supported at its ends and centrally loaded. The span between points of support was eight clear castellations i.e. 51.8 ins. as shown in Fig. 12 the central load being 2 tons. The test was conducted in a 50 ton Dennison compression machine, a photograph of which is shown in Fig. 11. Stresses were measured by 20 mm. Mahaak gauges, a pair of these gauges may be seen in the photograph. Deflections were measured by dial gauges graduated in one thousandths of an inch, these were so mounted on a horizontal steel rod that deflections at any desired part of the beam could be measured, these gauges are again shown in the photograph.

Mahaak or acoustic gauges, as they are sometimes called, were used in preference to electrical resistance

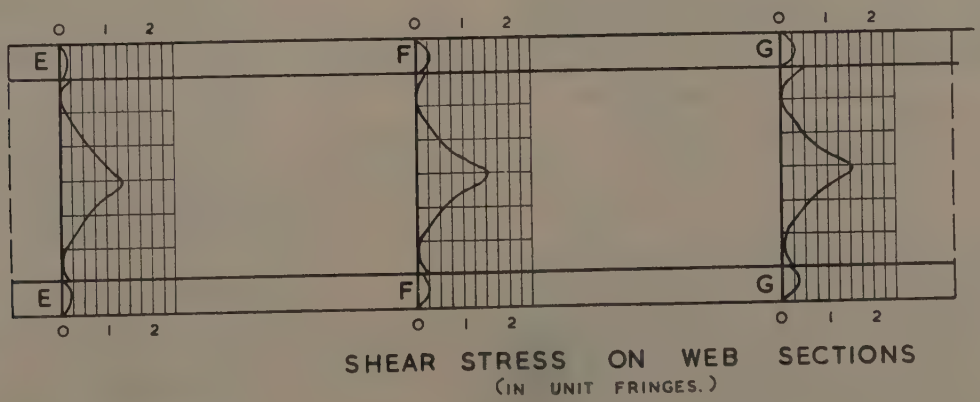


Fig. 10

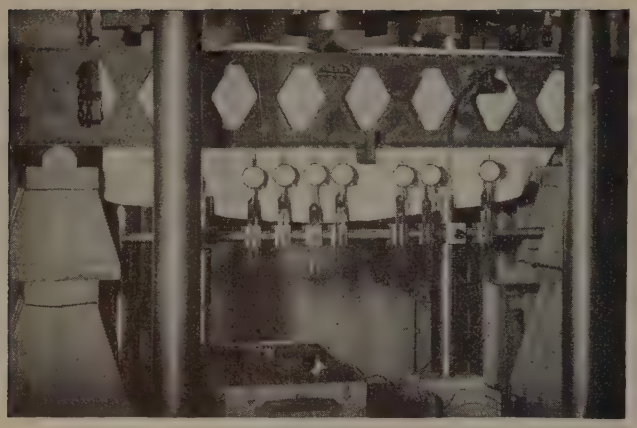


Fig. 11

strain gauges as the cost of these tests using the latter would have been prohibitive, owing to the large number of gauge positions. The extreme sensitivity and stability under varying temperature conditions of Mahaak gauges were added recommendations.

The flange stresses were determined by clamping a 20mm. gauge to the desired position on the flange, observing the initial reading of the instrument, loading to two tons on the machine, recording this reading and then finally unloading and checking the initial reading. In this manner a very accurate record of the flange stress at the required position was obtained. The gauge was then advanced to the next selected position and the procedure was repeated, in this manner the complete stress distribution along the flanges was recorded.

These experimental stresses are shown in Fig. 12, the full line drawn through the experimental points (shown as circles) represents the experimental stress distribution for the flanges, tension stresses are recorded as positive values and compressive stresses as negative.

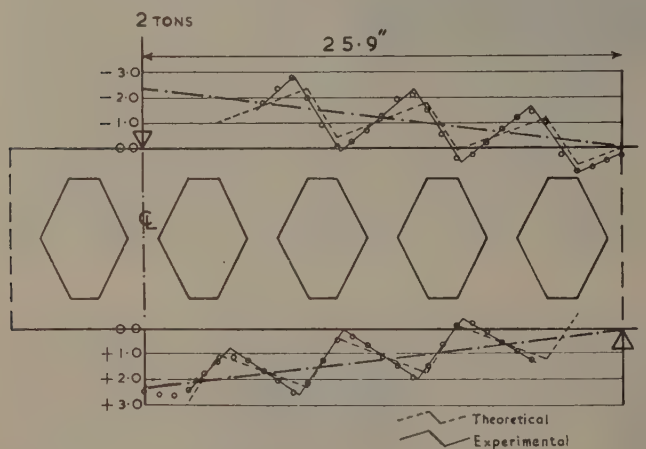


Fig. 12

The stresses around the edges of the castellations or vertical members were next investigated. In this case pairs of gauges were clamped to either side of the web so that all stresses due to torsion or transverse bending effects, if they existed, were eliminated by taking the mean of the gauge readings. These stresses are recorded in Fig. 13 and are shown as the full lines. Again tension stresses are indicated as of positive sign.

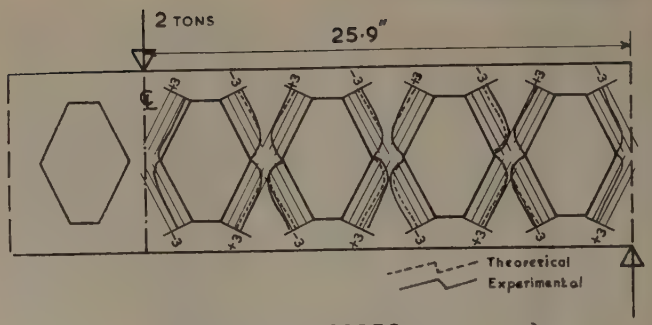


Fig. 13

From previous tests it was observed that the stress distribution over the major part of the sides of the vertical members was reasonably constant, stress concentrations occurring only at the extreme ends of the verticals. It was thus decided to reduce the number of observations along the edge of the verticals to eight, the extreme stress concentrations not being examined.

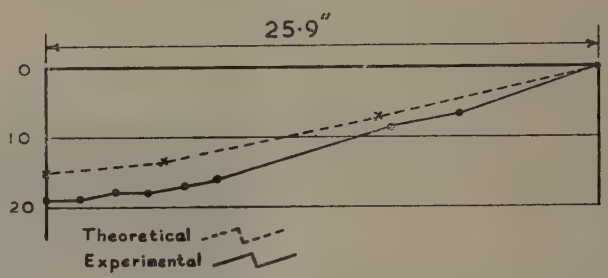


Fig. 14

Vertical deflections of the beam were recorded as shown by the full line in Fig. 14, the circles indicate actual experimental values.

The theoretical values for the above experiment were calculated as follows

Section Dimensions $B = 3''$, $d = 6''$, $t_2 = 0.377''$, $t_1 = 0.23''$

Top and Bottom Flange

Area $= 1.390$ in.^{2} using equation (33)

$\bar{y} = 1.170$ in. using equation (34)

Moment of Inertia using equation (35)

$I = 0.159$ in.^{4}

Verticals

$2b = 1.5d - 2t_2 = 8.246''$ using equation (36)

$a = 0.216d = 1.30''$ using equation (37c)

$k = 0.129t_1 = 0.0296$ using equation (37b)

Whence $I_c = 1.870$ ins.^{4} using equation (37a)

Using the above values in the relevant equations the following quantities were easily determined

$I^1 = 0.288$ ins.^{3} using equation (29c)

$\alpha^2 = 1.320$ using equation (29b)

$k^2 = 0.1145$ using equation (29d)

$\mu^2 = 1.328$ using equation (29e)

$\lambda = 0.00668$ using equation (29f)

Finally the vertical deflections of the beam were found from equation (29a) the load W being in this case 2 tons and are recorded in the following table.

Horizontal Distance in ins.	Vertical Deflection in 0.001 ins.
0.0	0.0
10.0	10.0
20.0	18.4
30.0	23.6
32.4	24.0

Table I

These theoretical deflections are plotted in Fig. 14 as the dashed line, it will be observed that reasonable agreement between theory and experiment exists.

The chord stress was determined from equation (38) on substituting the relevant quantities and was found to be $f_c = \pm x/11.5$ where x extends from 0 to 32.4 ins. i.e. f_c extends from 0 to 2.83 tons/sq. in. at the centre.

The bending stress due to the moment M_θ was next calculated, M_θ was found to be

$$M_\theta = Wh/4 = 3.24 \text{ tons ins.}$$

and then using equation (39)

$$fx = \frac{M_\theta \,.\, x \,.\, y}{1.08d \,.\, I}$$

where $y = 0.25d$—$\bar{y} = 0.33$ ins. $\therefore fx = 1.04x$ where x extends from —0.75″ to +0.75″. Whence the maximum values of fx were found to be $fx = \pm 0.78$ tons/sq. in.

The above bending stress was then superposed on the direct stress f_c, the resulting stress distribution in the flanges being shown as the dashed line in Fig. 12.

It remained but to examine the bending stresses in the verticals caused by the terminal moments M_θ. These bending stresses were given directly by equation (41) which on substituting relevant quantities gave eventually

$$fx = 15.4x/(1.30 + x)^2$$

where x extends from 0 to 4.12 ins. These values are recorded in Table II.

x in ins.	fx in tons/sq. in.
0	0
1	2.90
2	2.82
3	2.48
4	2.20

Table II

It is to be observed that these values for fx are the same for all the verticals as M_θ is approximately constant throughout the span of the beam. These values of fx were plotted for all castellations as the dashed lines in Fig. 13, where it will be seen that agreement between theory and experiment is reasonably good save for localised stress concentrations which of course cannot be explained by the above theory.

Two further tests were conducted, the spans being over ten and twelve clear castellations respectively. Flange stresses and stresses in the vertical members i.e. around the castellations were again recorded using Mahaak gauges and deflections were observed in the usual manner. The resulting stress distributions and deflections are plotted in Figs. 14-20 as the full lines. Again from the relevant data, the theoretical stresses and deflections were calculated and these are shown as the dashed lines in the corresponding Figures. It will be observed that agreement between theory and experiment is reasonably good especially in the cases of the stress distribution in the beam.

As agreement between theoretical and experimental values of deflection was only to within eighty per cent, it was decided to investigate more thoroughly the cause of this discrepancy. Moreover it was decided to investigate, experimentally, deflection values over greater spans than recorded in the previous tests.

The most probable cause of discrepancy between theoretical and experimental values of deflection is to be found in the dominant term of equation (29a) i.e.

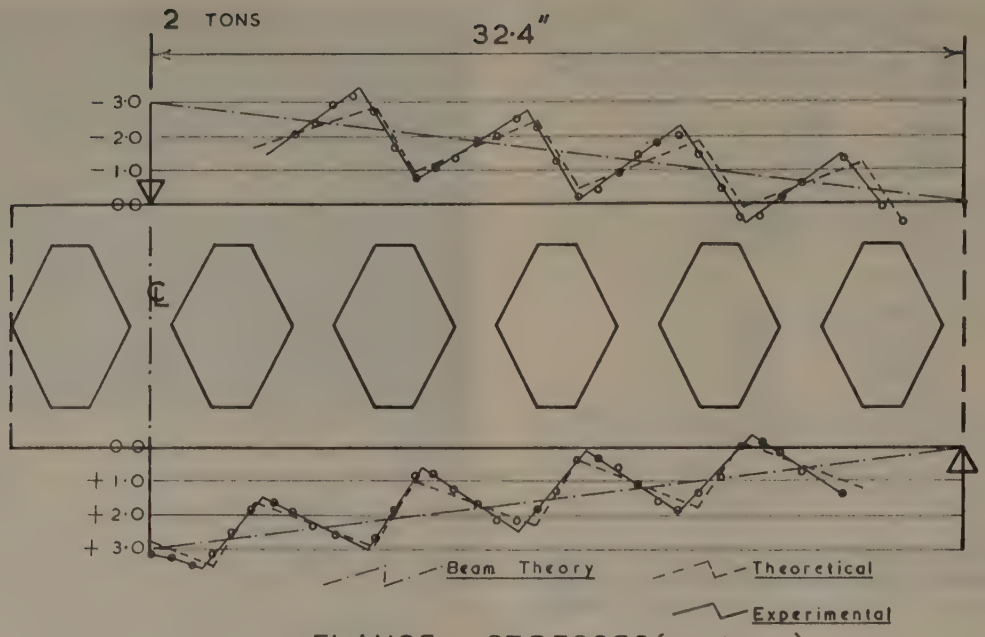
$$\lambda\left(\frac{L^2x}{8} - \frac{x^3}{6}\right)$$

Now

$$\lambda = \frac{4k^2\,\alpha^2}{\mu^2\,l^2} = C/l^2$$

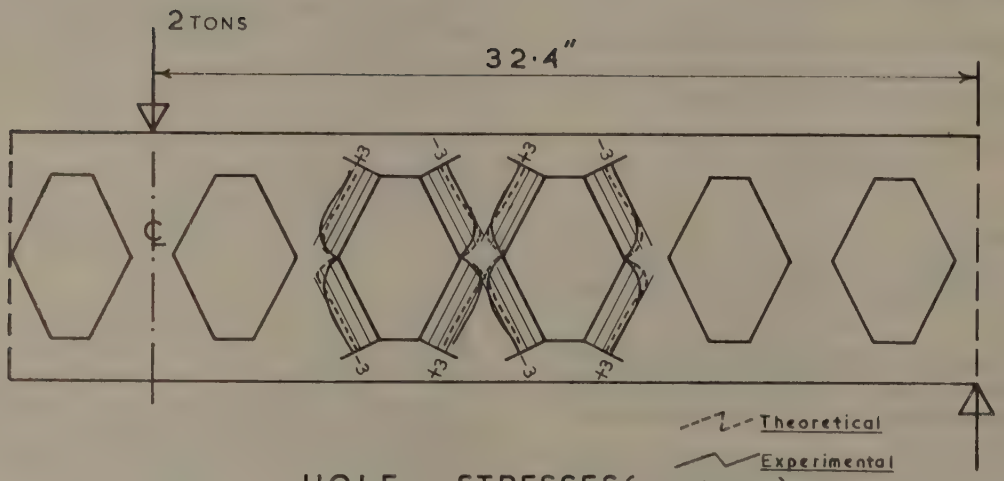
where $C = 4k^2\alpha^2/\mu^2$ is reasonably constant since $\frac{\alpha^2}{\mu^2} \simeq 1$ and $k^2 = I/A$. Thus the magnitude of the dominant term in the equation is controlled by $\lambda = C/l^2$ and is thus sensitive to changes in l. As described in an earlier part of this paper l was chosen as the distance between the neutral axes of the top and bottom flanges of the beam. Thus any modification in the assumed length of l would result in marked variation in the calculated deflections. If l was to be increased by 5 per cent, the resulting theoretical value for the deflection would be increased by some 11 per cent, further any error in the calculation of the value of I would result in the calculated value of the deflection being varied in the ratio $1/I$.

Further deflection experiments were conducted over increasing spans ranging from fourteen to twenty clear castellations. The resulting experimental values are plotted as the full lines in Fig. 21, the circles indicating actual observations, the theoretical values as given by equation (29a) being shown as the dashed lines in each case. It is obvious that as the span increases, agreement between theory and experiment is more close. This would seem to indicate that at smaller spans, shear is dominant and as shear has not of course, been considered specifically in the derivation of the theory, this could account for some of the discrepancy between theoretical and experimental values of deflection at smaller spans.



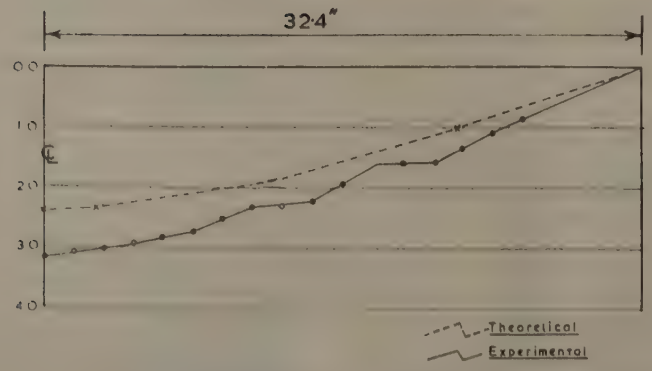
FLANGE STRESSES (TONS/SQ IN)

Fig. 15



HOLE STRESSES (TONS/SQ. IN.)

Fig. 16



DEFLECTIONS (IN 0·001 INS)

Fig. 17

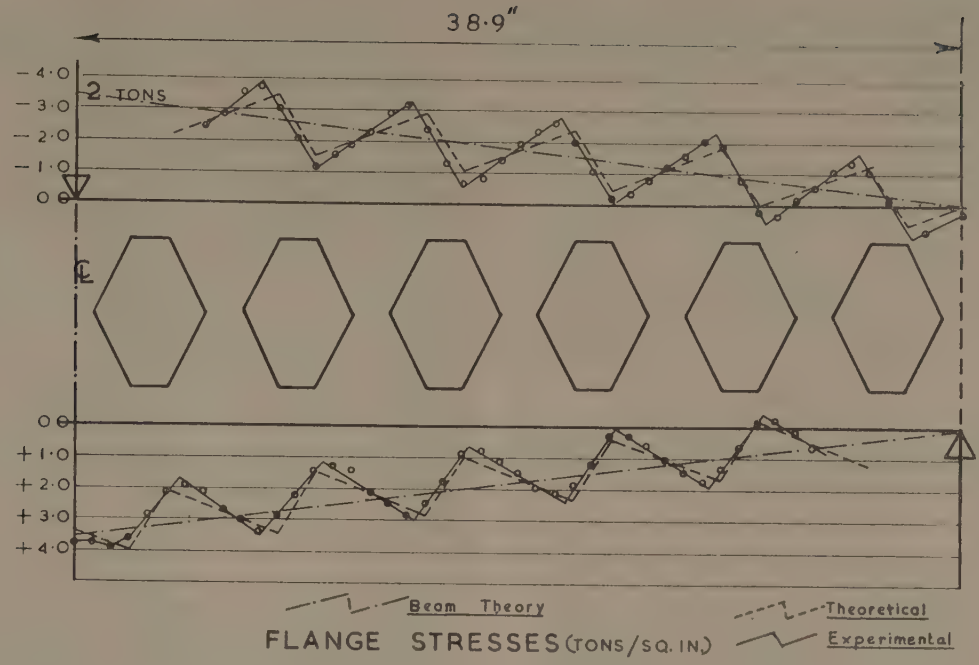


Fig. 18

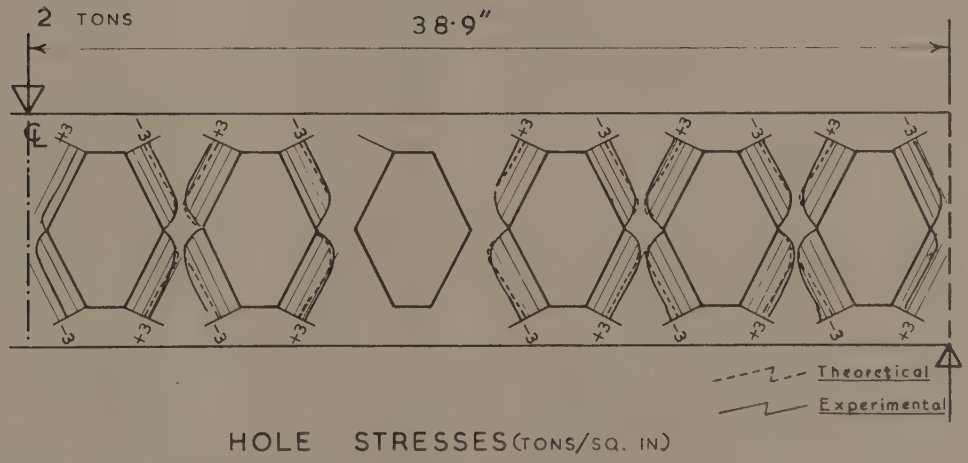


Fig. 19

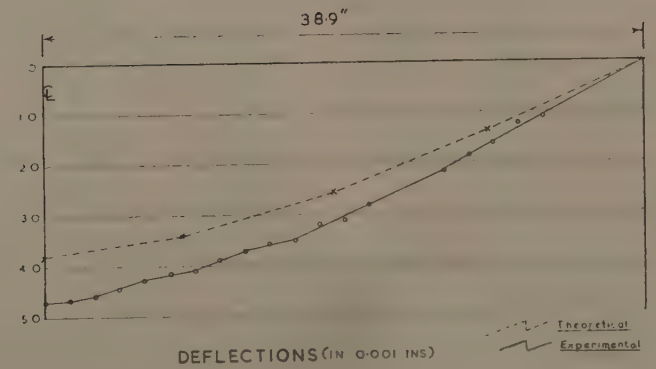


Fig. 20

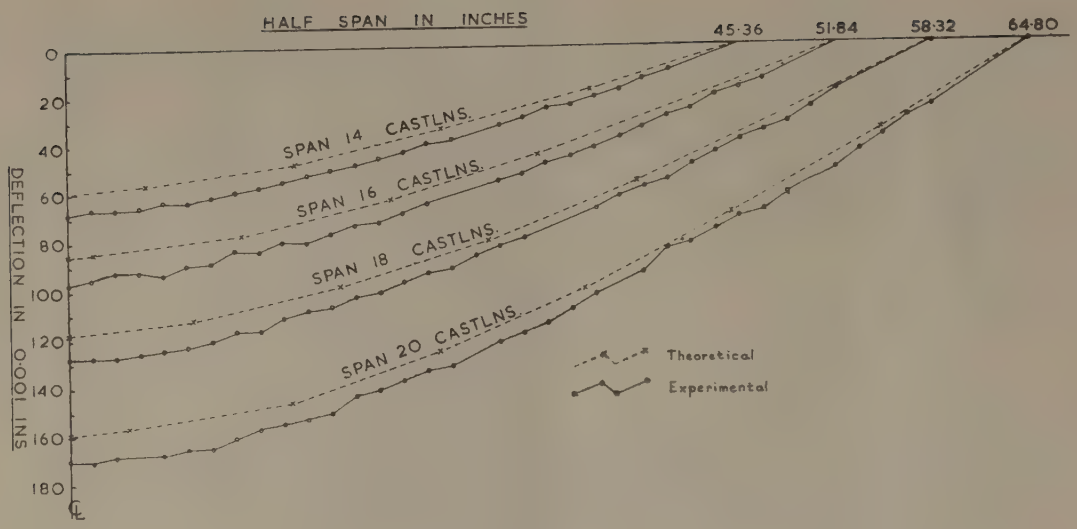


Fig. 21

Elementary Beam Theory

It is of some interest to compare the theoretical deflections as given by equation (29a) with those assuming that the castellated section behaves as a beam, the moment of inertia of which is that of its weakest section. Such assumptions are made by the manufacturers in preparing safe load tables. The weakest section occurs over the bridge of the castellation and the moment of inertia at this section will be designated by $\bar{I}$. This least moment of inertia may be easily calculated or selected from the standard tables supplied by the manufacturers. Under these assumptions the deflection of the centre of the beam will be given by the standard formula

$$y_c = WL^3/48E\bar{I}$$

in which W is the applied central load, L is the span length and $\bar{I}$ is the least moment of inertia of the section as a whole. The central deflections of the beam were calculated from equation (29a) and were compared with those calculated from the above elementary equation. The resulting values for various spans ranging from eight to twenty clear castellations are recorded in Table III.

Span in Castellation	Span in ins.	Deflection $yc_1 = WL^3/48E\bar{I}$	Deflection yc_2 by equatn. (29)	Ratio yc_2/yc_1
8	51.84	9.0	14.2	1.57
10	64.80	17.7	24.0	1.36
12	77.76	30.1	37.8	1.26
14	90.72	48.6	58.5	1.21
16	103.68	72.0	85.0	1.17
18	116.64	103.0	117.0	1.14
20	129.60	141.0	158.0	1.12

Table III
(All deflections are in 0.001 ins.)

In this table the end column gives the ratio of the central deflections as given by equation (29a) and the elementary beam form. It may be seen that as the span increases the ratio agreement between these two formulae is more close and one may postulate almost complete agreement for very large spans.

Now the bending stress as derived from the beam theory at a distance x from a support will be given by

$$fx = Wxy/2\bar{I}$$

where $\bar{I}$ is the least moment of inertia and $y = 0.75d$ is the extreme fibre distance from the neutral axis (recalling that d is the depth of the joist before cutting and welding and thus the final overall depth of the section is $1.5d$).

Applying this formula to the three beam spans in which stress was investigated, it is elementary to show that the maximum centre line stresses are as follows.

Span in ins.	Stress in tons/sq. in.
51.84	2.35
64.86	2.94
77.76	3.53

Table IV

These chord stresses are linear functions varying from zero at the supports to the maximum values, given in the table, at the centre lines and have been plotted in each case as the chain dotted lines in Figs. 12, 15 and 18. Now whilst at first sight, there appears to be a great variation between the stresses as given by this beam theory with those given by the present theory and the experimental results, it will be seen that, close to the centre line where the critical stress occurs, the agreement is quite good. In fact the chord stress as given by the Vierendeel theory is almost in complete agreement with the bending stress derived from the beam theory. It would thus seem that as far as determining the critical stress the beam theory as used by the manufacturers is sufficiently accurate for design purposes. The beam theory is, of course, unable to predict the vierendeel action which actually takes place and that the critical stress is actually located as a consequence slightly to the side of the point of loading. Nor does the beam theory give any indication of the internal stress system but, as predicted by present vierendeel theory, for longer

spans the critical stress distribution around the castellations is smaller than maximum centre line flange stress. This is clearly apparent in Fig. 18 where the critical centre line flange stress is about 3.8 tons/sq. ins. and the hole stresses are just over 3 tons/sq. in. as shown in Fig. 19. The theory presented in this paper is in turn unable of course to predict the stress concentrations which occur at the corners of the castellations but it is doubtful whether these are critical, being in fact purely localised. Thus it may be concluded that the maximum critical stress is in close agreement with that given by the beam theory, whilst deflections as given by the same theory are some 10 per cent—15 per cent less than those actually occurring when the spans are sufficiently long. As it is extremely unlikely that short spans will be much used in practice, in those cases in which deflection is critical, the deflection values as given by the beam theory might well need to be increased by the above percentage.

Conclusion

The experimental work described in this paper was limited to beams that were centrally loaded as this was considered to be the most critical condition for the case of simple loading of a simply supported beam. It may be concluded by comparing theoretical calculations with the available experimental evidence that castella *I* sections behave in the elastic domain as predicted by the theory presented in this paper i.e. a form of vierendeel action is taking place. Moreover that the present theory predicts the stress and deflection conditions as observed experimentally fairly accurately. Whilst the experimental work presented in this paper has been limited to one particular section size, the Authors in previous experimental work carried out in the Civil Engineering Department at the University of Glasgow have investigated the behaviour under simple bending conditions of various section sizes and the results have always been of the same nature as presented herein.

Acknowledgment

The Authors wish to acknowledge the manufacturers of Castella Beams, Messrs. Appleby-Frodingham, The United Steel Structural Company Ltd., Frodingham Works, Scunthorpe, Lincs. who kindly supplied the beams for testing.

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Institution Notices and Proceedings

GENERAL MEETING

A General Meeting of the Institution of Structural Engineers was held on Thursday, 3rd October, 1957, at 6 p.m., when the Presidential Address for the Session 1957-1958 was given by Professor Sir Alfred Pugsley, O.B.E., D.Sc.(Eng.), F.R.S., M.I.Struct.E., M.I.C.E., F.R.Ae.S.

Mr. J. Guthrie Brown, M.I.Struct.E., M.I.C.E., the retiring President, occupied the Chair.

After welcoming the many guests who were present at the meeting, the retiring President presented the following Institution awards gained during his year of office :

The Institution Silver Sessional Medal for the best paper read before the Institution or the Branches during the session 1955-56, to Mr. F. M. Bowen (Member of Council) and Mr. B. E. S. Ranger (Associate-Member of Council) for a paper, " Steelwork in Transit Shed 102, Southampton Docks."

The Institution Bronze Medal to Mr. J. M. Burke (Associate-Member) for a paper, " The New South Stand at Cardiff Arms Park."

The Institution Branch Award for the best paper from amongst those for which Branch prizes had been awarded, to Mr. J. M. Burke, for the above paper which was read before the Wales and Monmouthshire Branch.

Continuing, Mr. Guthrie Brown said he would very shortly be handing over to Sir Alfred Pugsley the honour and the various duties and responsibilities which fell to the President of their great Institution. It was customary for the retiring President to make a few remarks—something in the nature of a swan song.

Looking back over the list of Presidents for the past ten years, it was interesting to note that 70 per cent. had been consulting engineers. Some people might suggest the reason was that they had so little work to do that they enjoyed the rush and activities of a President's life. He preferred to think, however, that as a class they were so interested in the well-being of the Institution and so anxious for its continued prosperity that they readily sacrificed their business and spare time for the advancement of the Institution and its members. So far as he was concerned, he had been very glad to do his best for the Institution ; and if at the end of his year of office he had been able, in some way, to make the Institution better known

and appreciated in this country and overseas, then he was more than satisfied.

Members might like to hear a little of the extensive tour of Africa which he had carried out during August and September on behalf of the Institution. Major Maitland, unfortunately—due to the illness of Mr. Gray (Assistant Secretary)—was not able to accompany him, and the task of carrying out that tour single-handed, extending over some 16,000 miles, was quite a formidable and exhausting undertaking. Wherever he went, the absence of Major Maitland was regretted by members ; one felt it was rather like playing Hamlet, without the Prince.

During his tour he visited Uganda, Kenya and Rhodesia, that being the first time that any President of the Institution had entered those territories. He had felt, in some respects, that he was doing pioneer work like another and earlier Scot in Africa, Dr. Livingstone. The President had the advantage, however, that whilst Dr. Livingstone had risked being eaten by savages during his explorations, his own greatest risk was excessive over-eating, due to the hospitality of the members he had met ! The members in the Union of South Africa who had requested the visit of the President were also overwhelming in their friendliness and hospitality both to him and his wife. He attended lunches, dinners, cocktail parties, he gave lectures and made after-dinner speeches, and he met Mayors in their Town Halls. He was interviewed by the press, he visited dams, power stations, hydro-electric schemes, water purification works, factories, bridges and other engineering works ; he toured universities and technical colleges, visited native schools and patted the heads of the children ; in fact, he did everything that was expected of a President at Nairobi, Kampala, Salisbury, Kariba, Bulawayo, Johannesburg, Pretoria, Umtali, Durban, East London, Port Elizabeth and Cape Town.

The pace was terrific and the friendliness and hospitality overwhelming. Members in all parts of Africa were keenly interested in their Institution and in how the members in this country were faring. Greetings and good wishes were extended to him, not only by members, but by all the representatives of other kindred Institutions that he met. It was clear that a Presidential visit to Africa did nothing but good, and he had promised to put before the Council the request made on many occasions during his tour that a Presidential visit should take place at intervals of not more than five years.

His experience during his term of office was that, wherever he had gone, there had been nothing but kindness and friendly hospitality extended to him as President of the Institution, together with greetings and good wishes to the Institution and all its members. It was clear that as the years passed the Institution was increasing in prestige and importance and gaining even further respect from kindred Institutions. He had stressed at all times during his tour and on the various visits he had made to the Branches that members must make the public realise the important work done by structural engineers and must encourage young people to take up that very interesting profession.

While his year of office had been a busy one, it had been most enjoyable, thanks to the friendship, help and sound advice which he had received at all times from the members of the Council. He assured them that he was most grateful for their generous assistance. He also expressed his profound thanks to Major Maitland, who had been his special guide, philosopher and friend. Nothing had been too much for him to cope with in easing the Presidential burdens and keeping the President on the right lines. He would always remember with gratitude all that Major Maitland had done to assist him.

To the other members of the headquarters staff his thanks were also due ; they had at all times been friendly and helpful. He deeply regretted that the illness of Mr. Gray had occurred during his year of office, and would like to extend thanks for all he had done and to wish him every good luck in the future.

His principal duty on this occasion was to welcome his successor, Sir Alfred Pugsley, and to pass over to him the office and badge of President of the Institution of Structural Engineers. As all were aware, Sir Alfred was Professor of Civil Engineering in the University of Bristol. He was a Fellow of the Royal Society, and in 1956 he had received the well deserved honour of Knighthood for his services to engineering and research. His work in research was known throughout the world and the members were very proud that he was honouring the Institution by becoming its President (applause). Sir Alfred had for long had an interest in the Institution, having been connected with it since 1924—two years before he (Mr. Guthrie Brown) had joined. He had contributed many valuable papers to the proceedings and had played an active part not only in the Western Counties Branch, but in the various Committees at Headquarters.

He was respected and liked by all who knew him on the Council and would be equally liked when the various Branches made closer acquaintance with him during his Presidential tours. In his year of office he would enhance the reputation and prestige of the Institution by his dignity, charm and quiet sense of humour.

It was therefore with the greatest goodwill and with the utmost confidence that the affairs of the Institution would be in very capable hands that Mr. Guthrie Brown handed over the Presidential badge of office and expressed his best wishes for a happy and successful year.

Sir Alfred was invested with the Presidential badge, amid prolonged applause.

He then presented his Presidential Address.

Following the Address, Sir Alfred formally occupied the Chair.

Lieut.-Colonel G. W. Kirkland, M.B.E. (Vice-President) then proposed a vote of thanks to the Immediate Past President, a duty which afforded him great pleasure.

Mr. Guthrie Brown's year of office had been a memorable one for the Institution. It had been unusual ; and while all previous Presidents had contributed so very largely to the success of the Institution, each having built on the foundations of others, Mr. Guthrie Brown's year had been unique. He had inaugurated a number of new things in the course of his year of office and had enhanced the well-being of the Institution enormously. His Presidential Address was introduced in " technicolour," and there was colour in the printed version, for the very first time. Then he had inaugurated an increase of subscriptions ! He had saved the Institution from serious financial trouble and had enabled it to put in hand the improvement of the headquarters building. Mr. Guthrie Brown had then taken a " Cook's Tour " of far off places in the world, and had generously borne the

expense. The members could rest assured that his efforts had done a tremendous amount for the Institution's prestige.

Prior to taking office he was a man of few words. Those words had told, as could be seen from the results, and the members had every reason to be profoundly grateful to him for what had been a momentous year in the Institution's progress.

MR. E. N. UNDERWOOD, B.Sc.(Eng.), M.I.C.E. (Vice-President), seconding, said he was only too pleased to support the "understatement" by Col. Kirkland. There was an old saying that, if we wanted a job done efficiently and well, we should choose a busy man and one was quite sure that, in choosing Mr. Guthrie Brown as President during the last year, the Institution had proved very quickly the truth of that saying. The effort he had devoted—and one did not know how he had been able to find the time—to the welfare and prestige of the Institution was amazing.

(The vote of thanks was carried with enthusiasm).

MR. GUTHRIE BROWN thanked the meeting for their very kind response to the proposal by Col. Kirkland and Mr. Underwood. He was quite sure he did not deserve half of what had been said. It had been a very great pleasure to serve the Institution in the capacity of President, and he was most grateful for all the help and advice and kindness he had received from everybody.

MR. L. E. KENT, B.Sc.(Eng.), M.I.C.E. (Vice-President) proposed a vote of thanks to the President.

He supposed that, as every President came to the Chair, the members might be forgiven if they speculated on the subject of the forthcoming Presidential Address. They might also be forgiven if on that particular occasion they should have scored an "inner," if not a "bull." Fortunately, Professor Sir Alfred Pugsley had the happy knack of putting things in such a charming, direct and friendly manner that he had treated what he himself had described, in the words of more mundane people, an "academic" subject, in a most interesting way.

Sir Alfred had given his audience a wonderful evening. He had given a most comprehensive study of a subject with which, one supposed, only a few people in this country could deal. Not only had it been comprehensive, but it had been most entertaining. Mr. Kent confessed that he felt himself to be a pygmy in the presence of a giant in trying to thank Sir Alfred adequately for his address; therefore he would read it all the more carefully when it appeared in *The Structural Engineer* and he was sure that he would benefit from it. He did not think he would be alone in that respect.

If Sir Alfred gave to the Institution in the next twelve months, as one knew he would, such thoroughness as had gone into the preparation of his Address, the Institution would be very much the better for it at the end of that period.

It was a great pleasure to propose a vote of thanks to him.

MR. STANLEY VAUGHAN, B.Sc., M.I.C.E. (Past President) seconding, also paid tribute to the Institution's new President for a remarkably illuminatiug Address.

First he referred to a remark made by Sir Alfred at the very beginning of his address, when he had said that most engineers came across methods of design which were in general use but which seemed to be very far from rational. In such cases an engineer often tried to see whether he could not make some improvement on the generally accepted methods. He generally found, however, that this called for research involving equipment and facilities which were not usually available to him—and even if they were—he could not afford the time required for the necessary investigation. Moreover he might find that apart from the lack of research equipment he also lacked the essential mental equipment to carry through a successful research. It was very important, therefore, that the profession should include men who had the time and the equipment—physical and intellectual—to devote their minds to study the innumerable problems which faced us.

The members of the Institution were fortunate therefore to have as their new President one of the most able research workers in this country. Moreover, as he had shown in his Address, his approach to such problems was not an exclusively academic one. Clearly these were matters which could be solved only with the aid of great academic ability and facilities. But Sir Alfred had shown also that he understood the vital importance of presenting the results of research in a way which could be understood and applied by practising engineers.

In the course of his career Sir Alfred had acquired many honours, and Mr. Vaughan referred to three, not necessarily in chronological order nor in order of importance.

In the first place, all who knew him were delighted that, about a year ago, Sir Alfred's services were recognised by the honour of a Knighthood. In the engineering profession, unlike some other professions, the conferring of Knighthoods was comparatively rare. We could therefore be sure that if a Knighthood were given to an engineer he must have given outstanding service to engineering and to the country.

Another great honour which had been conferred on Sir Alfred was his election as Fellow of the Royal Society. Everyone knew that that was an honour which it was most difficult to acquire; only quite exceptional men had the opportunity to become a Fellow of that foremost scientific society of this country.

Now Sir Alfred was acquiring a further great honour, that of being elected to the Presidency of the Institution, and one felt quite sure that he would recognise it as a great honour. But although the Institution had conferred that honour upon him, he was conferring as great an honour upon all its members by agreeing to serve, and thereby accepting the onerous duties involved in guiding the affairs of the Institution for a year.

One could be perfectly sure that not only would the Institution gain greatly in prestige during Sir Alfred's year of office by having a man of his calibre as President, but also by his guidance of the Institution's affairs. It afforded Mr. Vaughan the greatest pleasure to second the vote of thanks to the President for a remarkably fine Presidential Address.

(The vote of thanks was accorded with acclamation).

ORDINARY GENERAL MEETING

An Ordinary General Meeting of the Institution of Structural Engineers was held at 11, Upper Belgrave Street, London, S.W.1., on Thursday, 24th October, 1957, at 5.55 p.m., Professor Sir Alfred Pugsley, O.B.E., D.Sc.(Eng.), F.R.S., M.I.Struct.E., M.I.C.E., F.R.Ae.S. (President) in the Chair.

The Minutes of the Ordinary General Meetings held on the 23rd May and 20th June, 1957, as published in the Journal, were taken as read, were confirmed and signed.

The following members were elected in accordance with the Bye-Laws. Will members kindly note that the elections, as tabulated below, should be referred to when consulting the Year Book for evidence of membership.

Graduates

Ali, Meer Mahmood, of London.
Ambrose, Derek, of Salisbury, Southern Rhodesia.
Awad, Osman el, of Khartoum, Sudan.
Banerjee, Harinath, of London.
Bell, Frank, of Newcastle upon Tyne.
Bielinski, Tadeusz, of Blackburn, Lancs.
Blundell, Robert Paul Ward, of Penzance, Cornwall.
Bowen, Lyndon Parry, of Ruislip, Middlesex.
Cundy, Christopher John, of London.
Currie, Malcolm Kenneth, of Derby.
Ellison, Morville Vernon, of London.
Farmer, Newton, of London.
Goodwin, Donald John, of Bradford.
Handyal, Kotrappa Maribasappa, of Dt. Durg, (M.P.) India.
Harkin, Michael Edward, of Dublin.
Horwood, Ernest John, of Pretoria, South Africa.
Huttmann, Edilbert, of Johannesburg, South Africa.
Joshi, Sharadchandra Martand, B.Sc.Poona, of Bombay, India.
Khan, Imam Haqqani, of London.
Lawton, Derek, of Stalybridge, Cheshire.
Luhar, Jashbhai Dahyabhai, of Dar-es-Salaam, Tanganyika.
Mitra, Ramgopal, B.Sc.Calcutta, of London.
Patel, Naginbhai Fakirbhai, of Kampala, Uganda.
Patel, Purushottam Fulabhai, of London.
Sanghvi, Vinayachandra Shantilal, of Rajkot, India.
Shimpi, Purushottam Udhava, of Poona, India.
Tan Hang Seng, of Ipoh, Perak, Malaya.
Wilgenbus, Hans Berndt, of Vanderbijl Park, South Africa.
Wiltshire, Dennis Edward, of Worcester Park, Surrey.

Associate-Members

Abbott, Samuel Louis, B.Sc.(Eng.) London, A.M.I.C.E., of London.
Behnke, Jozef, B.Sc.(Eng.) London, of London.
Burcham, Donald George, of Orpington, Kent.
Carter, Raymond Fred Sidney, of London.
Chotrani, Bhisham Mulchand, of Singapore.
Connelly, Terence Joseph, of Orpington, Kent.
Crewe, Leslie Walter, of Newport, Mon.
Docherty, David Gray, B.Sc.(Eng.) London, of Ellesmere Port, Cheshire.
Dykes, Alexander Robert, B.Sc.(Eng.) Glasgow, A.M.I.C.E., of East Kilbride, Lanarkshire.
Greenham, Ronald Gilbert, of Bristol.
Grover, Robert James Gray, of Wellington, New Zealand.
Hay, Christopher William Herbert, of Petts Wood, Kent.
Holmes, Roger, of Sale, Cheshire.
Kretsis, Kleomenis, of New Malden, Surrey.
Lefever, Frederick Arthur, of London.
Nassar, Joseph Jiries, of Achrafieh, Beirut-Lebanon.
Pengilly, Aubrey Herbert, B.Sc.(Eng.) London, A.M.I.C.E., of New Malden, Surrey.
Rennie, Douglas Yorke, B.Sc.(Eng.) London, A.M.I.C.E., of Garston, Watford, Herts.
Sutton, Benjamin Herbert Charles, B.Sc.(Eng.) London, of Clacton-on-Sea, Essex.
Taylor, Thomas Aelred, of Loughborough, Leics.
Ward, Leonard Charles, of Lancing, Sussex.
Wilson, Leslie Owen, A.M.I.C.E., A.M.I.Mun.E., of Croydon, Surrey.
Wyspianski, Kazimierz Marian, of London.
Yates, William Eric, of Nottingham.

Transfers

Students to Graduates

Anandalingam, Ramiah, of Jaffna, Ceylon.
Bagshaw, Grenville, of New Broughton, Nr. Wrexham, Denbs.
Broad, John Osborne, of Chesham, Bucks.
Burman, Ralph, of Scunthorpe, Lincs.
Chan Chiok Yuen, of Singapore.
Chandra, Tirtharenu, B.Sc.Calcutta, of London.
Clarke, Karl Nicholas Riley, of Nottingham.
Do Dai Hoy, of Singapore.
Doughty, Geoffrey, of Wrawby, Nr. Brigg, Lincs.
Dulson, William, of Scunthorpe, Lincs.
Fong Weng Cheong, of Singapore.
Hastings, Joseph William, of London.
Helsby, Charles Michael, of Derby.
Hunt, John, of Huddersfield, Yorks.
Laing, John Cranston, of Wishaw, Lanarkshire.
Latchem, Michael Ronald, of London.
Lee, Jack, of Stockport, Cheshire.
Morrison, Gordon William James, of Johannesburg, South Africa.
Rai, Sheopat, of Lucknow, India.
Readhead, Winn, of Scunthorpe, Lincs.
Rees, Allan Edward of Barry, Glamorgan.
Sahgal, Ravinder Kumar, of Urbana, Illinois, U.S.A.
Schaller, Brian George Allen, of Salisbury, Southern Rhodesia.
Seeto Yew Lee, of Singapore.
Shalders, Michael Bloy, of Enfield, Middlesex.
Singh, Parmatma, B.A.Punjab, of Patiala, (Pepsu) India.
Speakman, Alan, of Ollerton, Stockport, Cheshire.
Spring, Kevin Charles Fenton, of Wellington, New Zealand.
Thompson, Geoffrey, of Stafford.
Viswanathan, Puthezhath, of Madras, India.
Walker, Donald Geoffrey, of Derby.
Wilcock, Anthony Lewis, of Dewsbury, Yorkshire.
Williams, Michael Anthony, of London.
Woodmancy, Mary Catherine (Miss), of Bristol.

Students to Associate-Members

Julian, Leonard William, B.Sc.(Eng.) London, of North Wembley, Middlesex.
MacGregor, David, of Auckland, New Zealand.

Graduates to Associate-Members

Alcock, Donald Geoffrey, B.A.Cantab., of Toronto, Ontario, Canada.
Alexander, George, M.A.Cantab., A.M.I.C.E., of London.
Allington, Reginald Arthur, of Iver Heath, Bucks.
Ayres, Michael Walter David, of Kew Gardens, Surrey.
Ball, Walter Thomas, of Dunedin, New Zealand.
Beavington, Jack William, of London.
Bell, Brian Joseph, of Eastcote, Middlesex.
Beveridge, Andrew, B.Sc.(Civil) Glasgow, of Giffnock, Renfrewshire.

BHATTACHARYYA, Ajit Kumar, B.E. Calcutta, of Calcutta, India.
BHATTACHARYYA, Arishkumar, B.E.(Civil) Calcutta, of Derby.
BISS, Russell George, of Westbury-on-Trym, Bristol.
BLANCHARD, John Clifford, B.Sc.(Eng.) London, of Croydon, Surrey.
CLEAVELY, Albert Alexander, of Shoreham-by-Sea, Sussex.
CONDLIFFE, Sydney John, of Birmingham.
CORP, Roy, B.Sc.(Eng.) London, of Edinburgh.
CREBER, Allen Lindsay, of Southall, Middlesex.
DAINES, Alfred Lionel, of Cardiff, South Wales
DUNN, Horace William James, of London.
EASTERBROOK, Peter Lawrence, B.Sc.Wales, of Hanworth, Middlesex.
EVANS, Derek Norman, of Droitwich Spa, Worcestershire.
FITZGERALD, Gerald John, B.Sc.(Civil) Glasgow, A.M.I.C.E. of Edinburgh.,
GEACH, Trevor Trenley Ward, A.M.I.C.E., of Johannesburg, South Africa.
GREEN, Louis, of Redcar, Yorkshire.
HANSED, Jack, B.Sc.(Civil) Birmingham, of Manchester.
HOLDMAN, Roy, of Salford, Manchester.
HOMER, Albert Leslie, of Sutton Coldfield, Warwickshire.
HOOD, Derek Edward, of Bexley, Kent.
HUSSAIN, Syed Rafat, B.Sc., B.E., of London.
JANEWAY, Donald Alexander, of Harold Hill, Essex.
JONES, Malcolm, of Dewsbury, Yorkshire.
KANJEE, Sadroodeen Abdulla Alibhai, of London.
KOWALSKI, Tadeusz Gabriel, of Beckenham, Kent.
LEGGATT, Alec James, B.Sc.(Eng.) London, A.M.I.C.E., of London.
LONGRIGG, Thomas Derek, of Nairobi, Kenya.
LUXTON, Trevor Francis, B.Sc.(Eng.) London, of Downend, Bristol.
MCINTYRE, Douglas Arthur, of Chigwell Row, Essex.
MAGASINER, Alexander Sascha, B.Sc.(Eng.) Rand, of London.
MARTIN, John Neville, of Woking, Surrey.
MEADS, John Richard, of Pelsall, Nr. Walsall, Staffs.
MEARS, Terence Frederick, of Bexley, Kent.
MORNEMENT, Peter Clewes, B.A.Cantab., of Hove, Sussex.
MOSS-MORRIS, Arthur Louis, Ph.D. London, B.Sc.(Eng.) Rand, of Johannesburg, South Africa.
PITT, Peter Hubert, of Hampton, Middlesex.
READY, Reginald Frederick, of London.
RIDER, Brian Leonard, of Thundersley, Essex.
SCOTT, John Rodger, of Glasgow.
SHAW, Douglas Perston, B.Sc.(Civil) Glasgow, of Caithness, Scotland.
SMITH, Wilfred Collier, B.Sc.(Eng.) London, A.M.I.C.E., of Warrington, Lancs.
SNADDON, Robert Angus Anderson, of London.
STEEL, Dudley John, of Nairobi, Kenya.
STONE, Eric, of Urmston, Nr. Manchester.
SWADEN, Thomas, of London.
SWAN, Francis William Frederick, of London.
TIMSON, David John, B.Sc. Bristol, of London.
VIDES, Leslie, B.Sc.(Eng.) Cape, of London.
WATLING, Anthony John, of Cuffley, Herts.
WATSON, Fred, of Montreal, Canada.
WHITWORTH, Victor Percy, of London.
WILLIAMS, Kenneth Wilfred, of Bebington, Cheshire.
WILLIAMSON, Norman William, Ph.D., B.Sc.(Civil) Leeds, of York.
WILSON, Stanley George, of Hounslow, Middlesex.
WINTER, George Brian, B.Sc.(Civil) Birmingham, of Wilmslow, Cheshire.
WOOLFALL, William Arthur, of Wirral, Cheshire.
WOOLLARD, Malcolm William Thomas, of Buckhurst Hill, Essex.

OBITUARY

The Council regret to announce the deaths of Vivian Palmer HAUGHTON, John Ernest JONES, Ernest Harris TREMEWAN, Albert Edward WYNN, John LAIRD, Leopold Julian MARTIN (Members); John Alfred BRENTNALL, Cecil Guy CHURMS, Alfred Ernest HOLBROW (Retired Members) and Edward Norman Sandell ADAMS (Associate-Member).

FORTHCOMING MEETINGS

The following meetings will be held at 11, Upper Belgrave Street, London, S.W.1.

Thursday, December 12th, 1957
Maclachlan Lecture 1957

An Ordinary Meeting will be held at 6 p.m. for the presentation of the Maclachlan Lecture. The lecture, " Tandem Ferry Aprons for the Canadian Pacific Railway at Vancouver and Nanaimo, B.C., Canada," will be given by Mr. P. L. Easterbrook, B.Sc. (Associate-Member).

Thursday, December 19th, 1957

Ordinary General Meeting, 5 p.m. This meeting is for the election of members and is open only to corporate members of the Institution.

Thursday, January 9th, 1958

Ordinary Meeting at 6 p.m., when Mr. J. S. Terrington, B.Sc.(Eng.), A.M.I.Struct.E., A.M.I.C.E., will give a paper on " The Calculation of Bending and Torsional Effects in Girders."

Thursday, January 23rd, 1958

Joint Meeting with the Reinforced Concrete Association at 6 p.m., when Professor A. L. L. Baker, D.Sc.(Eng.), B.Tech., Hon. A.C.G.I., M.I.Struct.E., M.I.C.E., will give a paper on " The Work of the European Committee on Concrete."

Thursday, February 13th, 1958

Ordinary Meeting, 6 p.m., when Dr. K. C. Rockey, A.M.I.C.E., will give a paper on " Web Buckling and the Design of Webplates."

Thursday, February 27th, 1958

Ordinary General Meeting for the election of members, 5.55 p.m., followed by an Ordinary Meeting at 6 p.m., when Mr. J. F. Eden, B.Sc.(Eng.), M.I.Mech.E., and Mr. D. Bishop, A.M.I.C.E., A.R.I.C.S., will give a paper on " The Problem of Mechanical Handling in Building Operations."

Members wishing to bring guests to the Ordinary Meetings announced above are requested to apply to the Secretary for tickets of admission.

EXAMINATIONS—JULY, 1957—OVERSEAS CENTRES

The examinations were held in July, 1957, overseas at the following centres: Accra, Alor Star, Aligarh, Auckland, Beirut, Bombay, Brisbane, Bulawayo, Calcutta, Cape Town, Chingola, Christchurch (N.Z.), Colombo, Cooma, Dar-Es-Salaam, Dunedin, Durban, East London (South Africa), Gwelo, Hong Kong, Johannesburg, Kampala, Kingston (Jamaica), Kuala

Lumpur, Lahore, Los Angeles (California), Madras, Montreal, Nairobi, Ottawa, Port Elizabeth (S. Africa), Qatar-Doha, Salisbury (S. Rhodesia), Singapore, Toronto, Trinidad, Wellington (N.Z.), Welkom (Orange Free State).

Fifty candidates took the Graduateship Examination, and 107 took the Associate-Membership Examination. Of these, 32 passed the Graduateship Examination, and 29 passed the Associate-Membership Examination. The names of the successful candidates are :

Graduateship Examination

Ambrose, Derek Nelson.
Ambulkar, Manohar R.
Anandalingam, Ramiah.
Bhandari, Narindar Kumar.
Chan Chiok Yuen.
Cheng Chee Teck.
Cordeiro, John Joseph.
Do Dai Hoy.
Fong Weng Cheong.
Handyal, Kotrappa Maribasappa.
Horwood, Ernest John.
Huttmann, Edilbert.
Joshi, Sharadchandra Martand.
Kale, Anant Laxman.
King, Brian Winston.
Laing, Eric Charles.
Luhar, Jashbhai Dahyabhai.
Middleton, Kenneth Grant.
Miu Jack Hing.
Morrison, Gordon Wm. James.
Patel, Naginbhai Fakirbhai.
Rai, Sheopat.
Raman, Dorai.
Sanghvi, Vinayachandra Shantilal.
Seeto Yew Lee.
Shimpi, Purushottam Udhava.
Singh, Parmatma.
Spring, Kevin Charles Fenton.
Tan Hang Seng.
Viswanathan, Puthezhath.
Wilgenbus, Hans Berndt.
Young, Raymond Brian.

Associate-Membership Examination

Albert, Kenneth Leo.
Alexander, Kunchattil Chacko.
Alexander, Wm. Ernest Walter.
Ball, Walter Thomas.
Banerji, Biswa Nath.
Chan Weng Onn.
Chandola, Shambhu Prasad.
Chotrani, Bhisham Mulchand.
Evans, Clifford John.
Geach, Trevor Trenley Ward.
Guha, Sukumar.
Hasan, Mohammed Mazharuddin.
Hay, Christopher Wm. Herbert.
Ho Peng.
Jagger, Albert Charles.
Joffe, Isaac Wolf.
Kinnaird, George Alfred.
Kulkarni, Shrikrishna S.
MacGregor, David.
Malloch, Trevor Stuart.
Moss-Morris, Arthur Louis.
Nassar, Joseph Jiries.
Ng Eng Hean.
Priddey, Harry Walter.
Steel, Dudley John.
Stone, William Dennis.
Tantry, Prabhakar Vasudez.
Van Berkel, Gerardus Johannes.
Venier, John.

PRIZES—JULY 1957 EXAMINATIONS

The Council have awarded the following prizes in respect of the Examinations held in July, 1957 :

Andrews Prize (For the candidate who obtains the highest aggregate of marks in the Associate-Membership Examination, passing in all subjects)
Peter Thomas Chadd, of London.

Husband Prize (For the candidate who takes the whole of the Associate-Membership Examination, passes in all subjects, and obtains the highest marks in the paper " Structural Engineering Design and Drawing ")
Donald Alexander Janeway, of Romford, Essex.

Wallace Premium (Senior) (For the candidate who takes the whole of the Associate-Membership Examination, passes in all subjects, and obtains the highest marks in the paper " Theory of Structures (Advanced)"
Graham John Smith, of Birmingham.
P. T. Chadd, of London.

Wallace Premium (Junior) (For the most successful candidate in the Graduateship Examination, passing in all subjects)
Frank Bell, of Newcastle-on-Tyne. "

BRANCH NOTICES

LANCASHIRE AND CHESHIRE BRANCH

The following meetings have been arranged :

Monday, 16th December, 1957

Mr. S. Richards, A.M.I.Struct.E., and Mr. N. Lancaster will give a paper entitled " A Review of the Structural Steelwork in the ' Seraphim ' Extensions at Appleby-Frodingham."

Tuesday, 7th January, 1958

Mr. E. Ll. Morgan, M.Sc.Tech., A.M.I.Struct.E., A.M.I.Mun.E., on " Shrinkage in Soils."

Wednesday, 12th February, 1958

Mr. D. M. Brotton, B.Sc.(Eng.), Ph.D., A.M.I.Struct.E., on " The Use of the Electronic Digital Computer in Structural Calculations."

Lectures will commence at 6.30 p.m. and will be preceded by light refreshments. All the above meetings will take place at the College of Science and Technology, Manchester.

MERSEYSIDE PANEL

The following meeting has been arranged :

Wednesday, 5th February, 1958

Mr. R. B. L. Smith, B.Sc.Tech., A.M.I.Struct.E., on " Shear Effects in Reinforced Concrete Beams." At the College of Building, Clarence Street, Liverpool. Light refreshments will be available from 6 p.m., and the meeting will commence at 6.45 p.m.

Joint Hon. Secretaries: J. L. Robinson, A.M.I.Struct.E., 314, Northenden Road, Sale, Manchester. M. D. Woods, A.M.I.Struct.E., 58, Spring Gardens, Salford, 6.

MIDLAND COUNTIES BRANCH

The following meetings have been arranged :

Friday, 24th January, 1958

Mr. F. M. Bowen, M.I.Struct.E., M.I.C.E., Assoc.I.Mech.E. (Member of Council) and Mr. B. E. S. Ranger, A.M.I.Struct.E., A.M.I.C.E. (Associate-Member of Council) on "Steelwork in Transit Shed 102, Southampton Docks." At the James Watt Memorial Institute, Great Charles Street, Birmingham, at 6 p.m.

Tuesday, 4th February, 1958

Joint Meeting with the Reinforced Concrete Association, Midland Counties Branch, at the Midland Institute, Birmingham, 6 p.m.

Friday, 21st February, 1958

Joint Meeting with the Birmingham and Five Counties Architectural Association. Mr. G. Winteringham, Dipl.Arch.Birm., A.R.I.B.A., and Mr. Bryan W. Cooper, B.Sc., A.M.I.Struct.E., on " Some Recent Building in Northern Europe." At the Royal Birmingham Society of Artists Galleries, New Street, Birmingham, 6 p.m.

Friday, 28th February, 1958

Mr. F. M. Easton, A.M.I.Struct.E., A.M.I.C.E., Mr. E. M. Lewis, A.C.G.I., A.M.I.W., and Mr. D. T. Wright, B.A.Sc., M.S., Ph.D. will give a paper entitled " Some Notes on the Use of High Pre-Load Bolts in the United Kingdom." At the James Watt Memorial Institute, Great Charles Street, Birmingham, 6 p.m.

Hon. Secretary : J. R. Chaffer, M.I.Struct.E., 107, Jockey Road, Sutton Coldfield, Warwickshire.

GRADUATES' AND STUDENTS' SECTION

The following meetings have been arranged :

Friday, 6th December, 1957

Joint meeting with the Junior Section of the Institution of Municipal Engineers. Mr. W. J. Young, B.A.I., on " The Cement Gun and its Use in the General Field of Structural Engineering."

Friday, 7th February, 1958

Mr. J. E. C. Farebrother, M.I.Struct.E., on " Prestressing and the Systems in Common Use Today." Both meetings will be held at the Birmingham Exchange and Engineering Centre, Stephenson Place, Birmingham, at 6.30 p.m.

Hon. Secretary : F. A. Butterworth, " Roscrea," Tansey Green, Pensnett, Brierley Hill, Staffs.

NORTHERN COUNTIES BRANCH

The following meetings have been arranged :

Tuesday, 3rd December, 1957

At Middlesbrough. Mr. F. M. Bowen, M.I.Struct.E., M.I.C.E., Assoc.I.Mech.E. (Member of the Council) and Mr. B. E. S. Ranger, A.M.I.Struct.E., A.M.I.C.E. (Associate-Member of Council) on " Steelwork in Transit Shed 102, Southampton Docks."

Wednesday, 4th December, 1957

The above paper will be repeated at Newcastle.

Wednesday, 15th January, 1958

At Middlesbrough. Joint meeting with the Institution of Civil Engineers. Mr. J. O. C. Ritchie on " Water Towers."

Thursday, 16th January, 1958

At Newcastle. Joint meeting with the Northern Architectural Association, at Higham Place, Newcastle. Lecture to be arranged.

Tuesday, 4th February, 1958

At Middlesbrough.

Wednesday, 5th February, 1958

At Newcastle. Mr. W. H. Chilton, A.M.I.Struct.E., on " Some Structural Aspects of Nuclear Reactors." Meetings in Middlesbrough will be held in the Cleveland Scientific and Technical Institution and meetings in Newcastle (except where noted) in the Neville Hall. All meetings commence at 6.30 p.m., preceded by buffet tea at 6 p.m.

Hon. Secretary : H. W. Dowe, A.M.I.Struct.E., 143, Laburnum Road, Redcar, Yorks.

NORTHERN IRELAND BRANCH

The following meetings have been arranged :

Monday, 9th December, 1957

Meeting to be held with the Northern Ireland Association of the Institution of Civil Engineers at Queen's University, Belfast. Professor J. L. Montrose on " The Interpretation of Contracts and Arbitration."

Tuesday, 7th January, 1958

Tuesday, 4th February, 1958

Details to be arranged.

Hon. Secretary : A. H. K. Roberts, B.A., B.A.I., M.I.Struct.E., M.I.C.E.I., " Barbizon," 26, Dunlambert Park, Belfast.

SCOTTISH BRANCH

The following meetings have been arranged :

Tuesday, 17th December, 1957

Mr. O. A. Kerensky, B.Sc., M.I.Struct.E., M.I.C.E., on " Design of Plate Girders."

Tuesday, 21st January, 1958

Mr. P. Russell, B.Sc., A.M.I.C.E., M.Inst.H.E., on " Recent Concrete Construction in Scotland."

Friday, 14th February, 1958

Joint meeting with the West of Scotland Branch of the Institution of Civil Engineers and the West of Scotland Branch Institute of Welding. Mr. Douglas Lax, M.I.Struct.E., and Mr. J. F. C. Swansbourne, A.M.I.C.E., on " Bridges in Iraq."

All the above meetings will be held at the Institution of Engineers and Shipbuilders, 39, Elmbank Crescent, Glasgow, 7.0 p.m.

Hon. Secretary : W. G. Cantlay, B.Sc.(Eng.), A.M.I.Struct.E., A.M.I.C.E., 3, Blairbeth Terrace, Burnside, Glasgow.

SOUTH WESTERN COUNTIES BRANCH

The following meetings have been arranged :

Friday, 6th December, 1957

Mr. Clifford E. Saunders, M.I.Struct.E., on " Some Unusual Structural Engineering Problems." At the

Duke of Cornwall Hotel, Plymouth, 6 p.m. Tea will be served at 5.30 p.m.

Friday, 17th January, 1958

Joint meeting with the Institution of Civil Engineers. Mr. W. R. Hockaday, M.I.C.E., on "Lifting Equipment." At the Duke of Cornwall Hotel, Plymouth, 6 p.m. Tea will be served at 5.30 p.m.

Friday, 14th February, 1958

Meeting will be held in Truro, details to be announced.

Hon. Secretary: C. J. Woodrow, J.P., "Elstow," Hartley Park Villas, Mannamead, Plymouth, Devon.

WALES AND MONMOUTHSHIRE BRANCH

The following meetings have been arranged:

Tuesday, 3rd December, 1957

At Cardiff. Joint meeting with the Institute of Welding. Mr. A. V. Hooker, M.I.Struct.E., M.I.C.E. (Past Chairman), "Recent Thoughts on Structural Welding."

Wednesday, 11th December, 1957

At Swansea. Joint meeting with the Institution of Civil Engineers.

Wednesday, 15th January, 1958

At Swansea. Mr. E. M. Lewis, A.C.G.I., A.M.I.W., "Some Notes on the Use of High Pre-Load Bolts in the United Kingdom."

Tuesday, 4th February, 1958

At Cardiff. Joint meeting with the Institution of Municipal Engineers. Mr. C. D. C. Braine, B.Sc., M.I.Struct.E., M.I.C.E., on "Structural Aspects of the Design of a Sea Outfall."

Meetings at Cardiff will be held at the South Wales Institute of Engineers, Park Place, at 6.30 p.m. Meetings at Swansea will be held at the Mackworth Hotel at 6.30 p.m.

Hon. Secretary: K. J. Stewart, A.M.I.Struct.E., A.M.I.C.E., 15, Glanmor Road, Swansea.

WESTERN COUNTIES BRANCH

The following meetings have been arranged:

Friday, 6th December, 1957

Mr. R. G. Taylor, B.Sc.(Eng.), M.I.Struct.E., A.M.I.C.E., on "Tubular Structures."

Friday, 3rd January, 1958

Mr. G. B. Smedley, B.Sc.(Tech.), A.M.I.Struct.E., A.M.I.C.E., on "Construction of a Prestressed Concrete Circular Tank."

Tuesday, 4th February, 1958

Annual Dinner Dance to be held at the Ashton Court Country Club, near Bristol. The above meetings will be held in the Small Lecture Theatre, University Engineering Laboratories, University of Bristol, at 6 p.m., preceded by tea at 5.30 p.m.

Hon. Secretary: E. Hughes, M.I.Struct.E., 23, Southdown Road, Westbury-on-Trym, Bristol, 9.

YORKSHIRE BRANCH

The following meetings have been arranged:

Wednesday, 11th December, 1957

At Leeds. Mr. G. B. Godfrey, A.M.I.Struct.E., A.M.I.C.E., A.M.I.Mun.E. (Associate-Member of Council), on "Post-War Developments in German Steel Bridges and Structures."

Thursday, 12th December, 1957

The above meeting will be repeated at Sheffield.

Wednesday, 15th January, 1958

At Leeds. Mr. D. Beckett, B.Sc.(Eng.), Grad.I.C.E., and Mr. B. J. S. Walls, B.Sc.(Eng.), Grad.I.C.E.: "An Introduction to Pre-Stressed Concrete in Highway Engineering."

Wednesday, 19th February, 1958

At Leeds. Three short papers on "The Reconstruction of the Main Stand at Elland Road Football Ground" will be contributed by the Architect, the Reinforced Concrete Contractor and the Structural Steelwork Contractor.

Wednesday, 26th February, 1958

At Scunthorpe. Mr. Donovan H. Lee, B.Sc.(Eng.), M.I.Struct.E., M.I.C.E., M.I.Mech.E. (Member of Council) on "The Advantages and Disadvantages of Structural Steelwork, Reinforced Concrete and Pre-Stressed Concrete." Meetings at Leeds will be held at the Central Electricity Authority Offices, Whitehall Road, 6.30 p.m. Meetings at Sheffield will be held at the Royal Victoria Hotel, 6.30 p.m. The meeting at Scunthorpe will be held at the Blue Bell Hotel, 6.30 p.m.

Hon. Secretary: W. B. Stock, A.M.I.Struct.E., 34, Hobart Road, Dewsbury, Yorks.

UNION OF SOUTH AFRICA BRANCH

Hon. Secretary: A. E. Tait, B.Sc., A.M.I.Struct.E., A.M.I.C.E., P.O. Box 3306, Johannesburg, South Africa.

During weekdays Mr. Tait can be contacted in the City Engineer's Department, Town Hall, Johannesburg. Phone 34-1111, Ext. 257.

Natal Section Hon. Secretary: J. C. Panton, A.M.I.Struct.E., A.M.I.C.E., c/o Dorman Long (Africa) Ltd., P.O. Box 932, Durban.

Cape Section Hon. Secretary: R. F. Norris, A.M.I.Struct.E., African Guarantee Building, 8, St. George's Street, Cape Town.

EAST AFRICAN SECTION

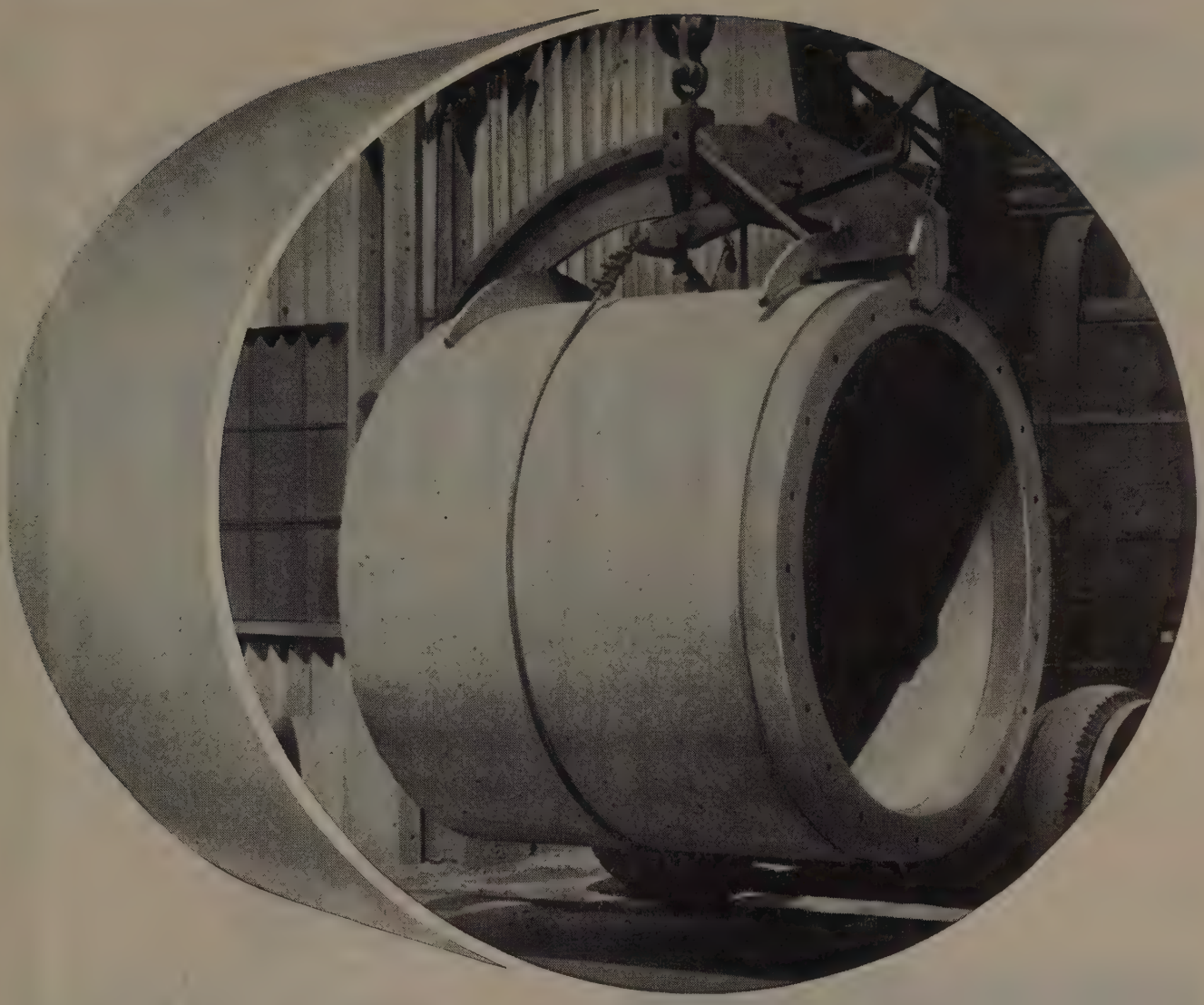
Chairman: R. A. Sutcliffe, M.I.Struct.E.

Hon. Secretary: K. C. Davey, A.M.I.Struct.E., P.O. Box 30079, Nairobi, Kenya.

SINGAPORE AND FEDERATION OF MALAYA SECTION

Chairman: T. Karmakar, M.I.Struct.E.

Hon. Secretary: W. N. Cursiter, B.Sc., A.M.I.Struct.E., c/o Redpath Brown and Co. Ltd., P.O. Box 648, Singapore.



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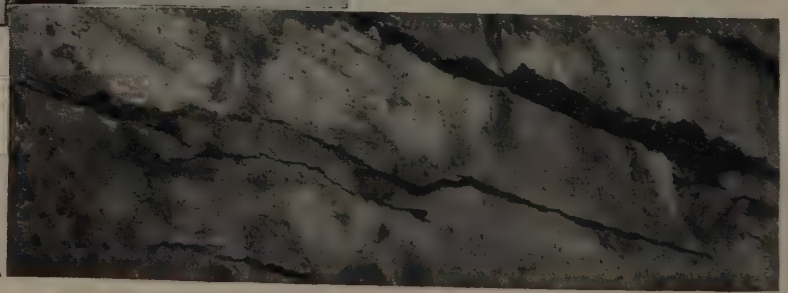

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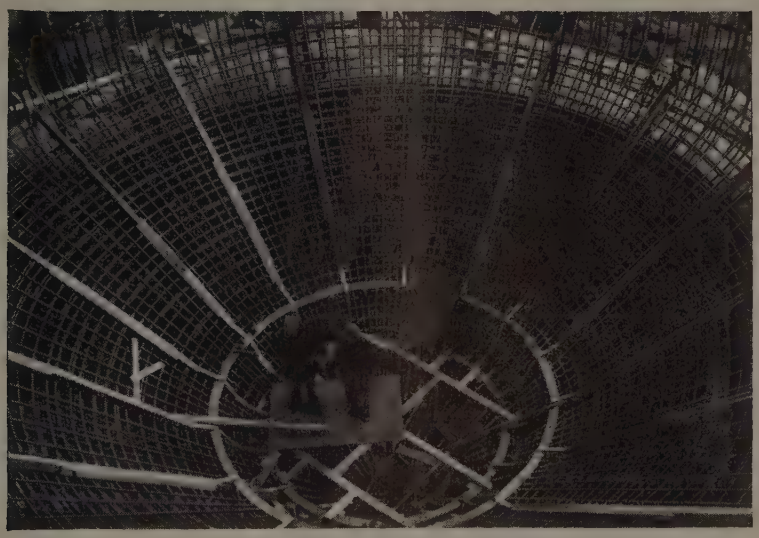

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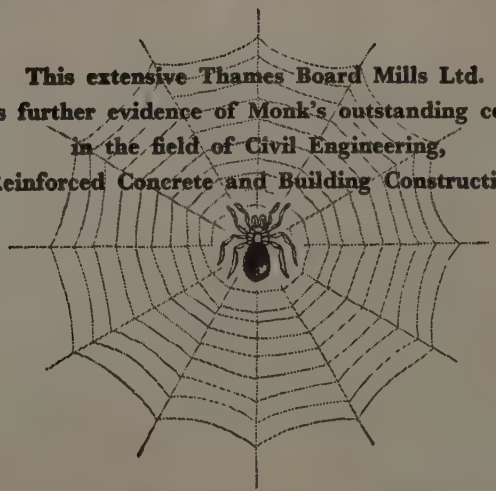

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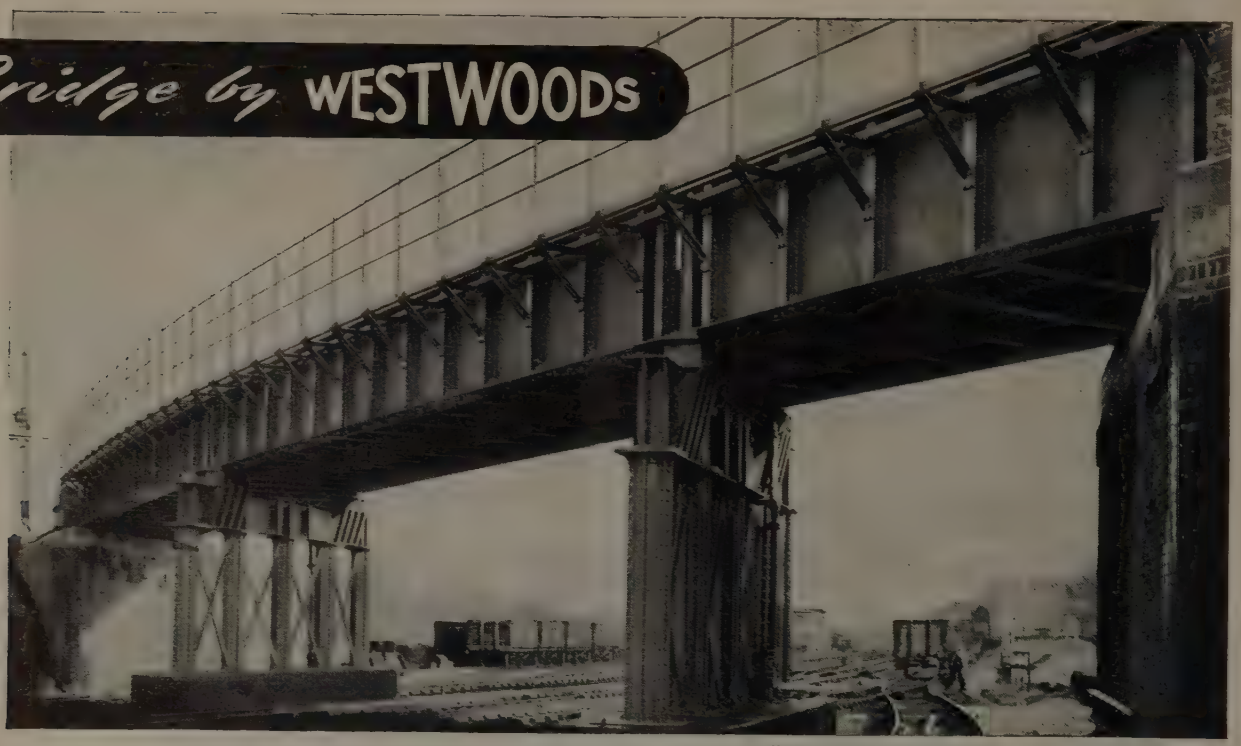

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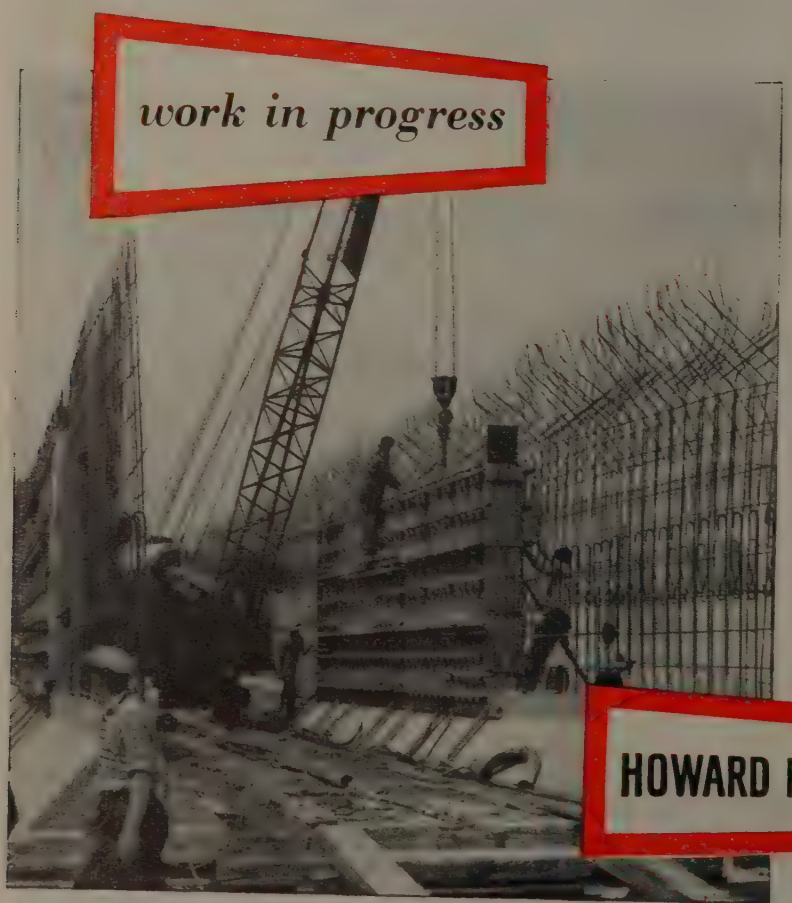

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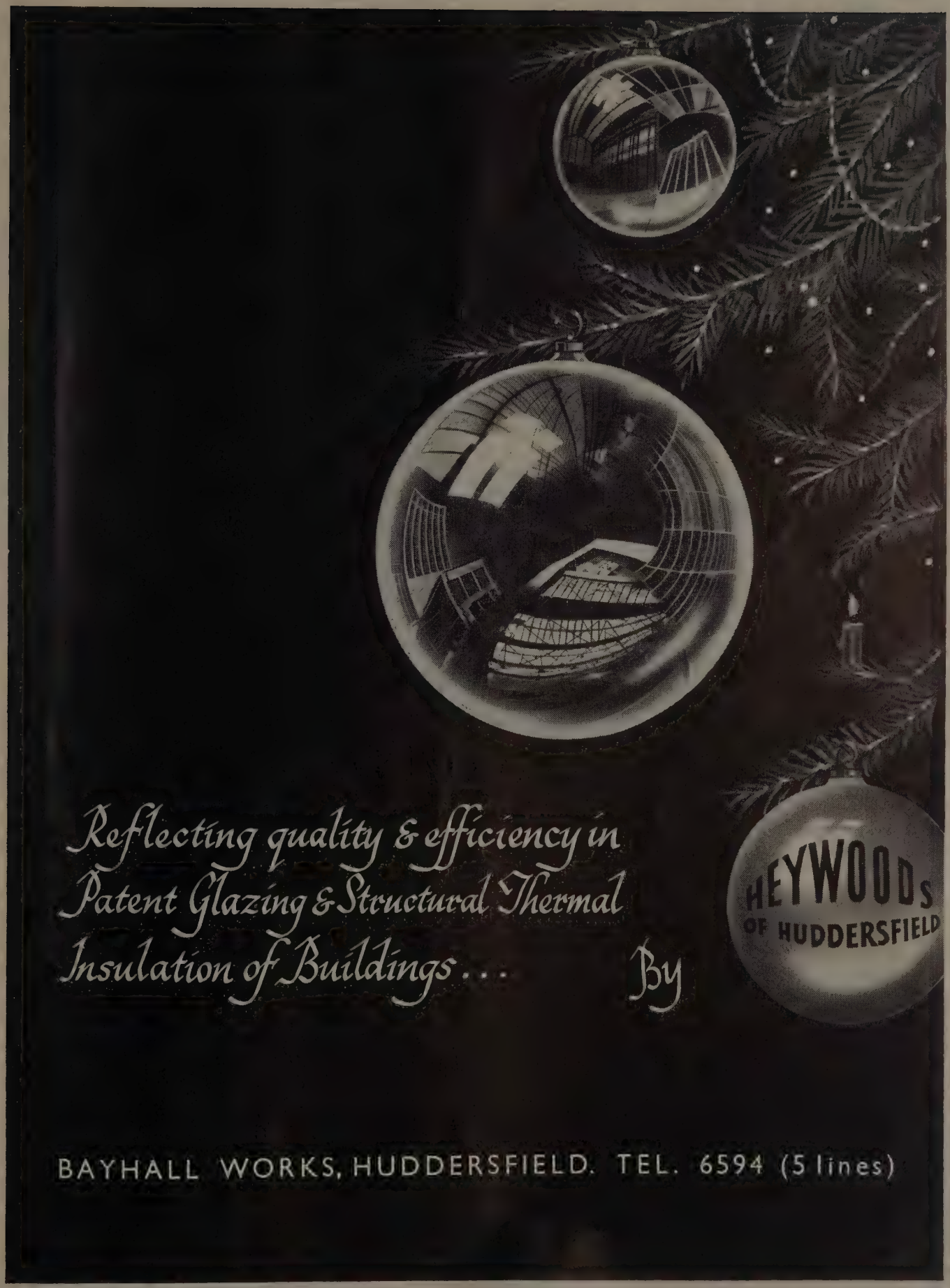
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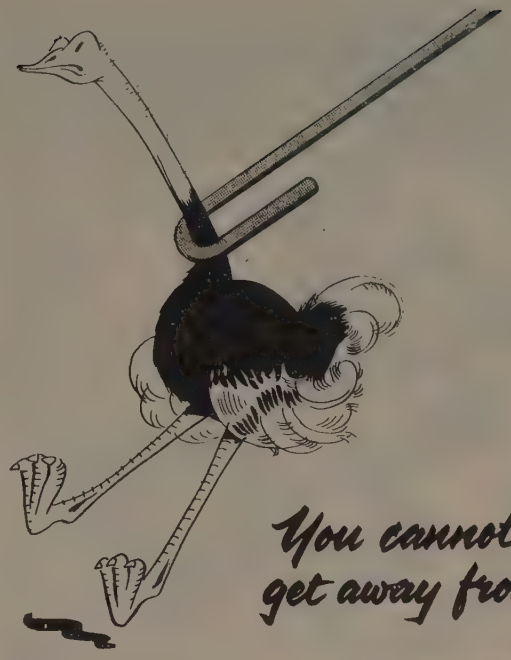

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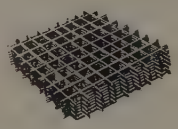

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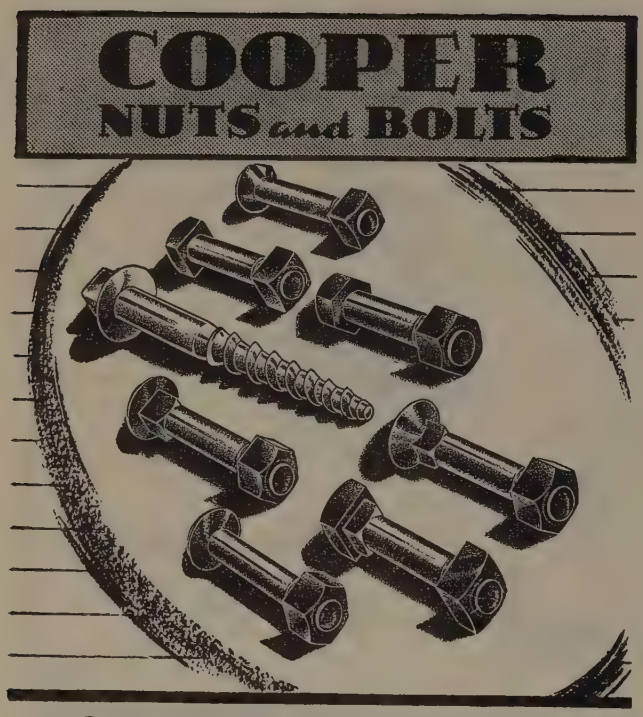

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